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BULLETIN

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American Association *of* Petroleum Geologists

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THE BULLETIN

of the

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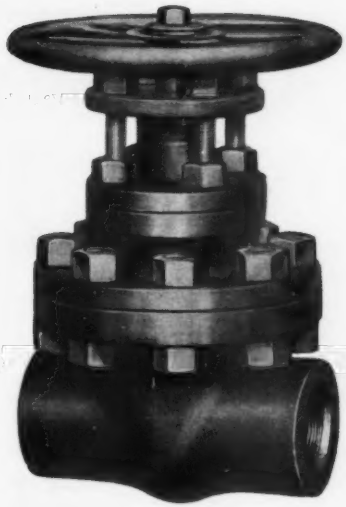

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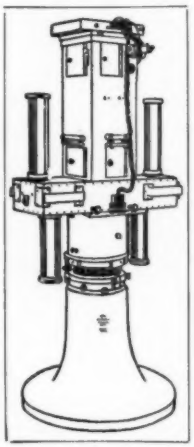

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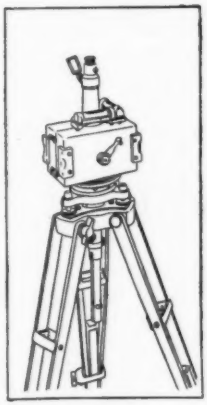

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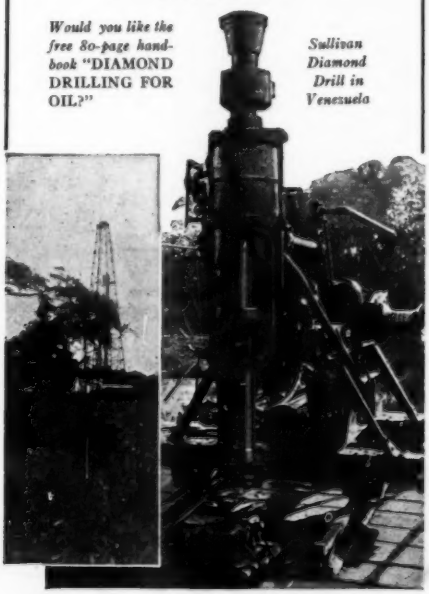

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GRAVITY ANOMALIES AND PETROLEUM EXPLORATION BY THE GRAVITATIONAL PENDULUM[1]

M. K. HUBBERT[2] AND FRANK A. MELTON[3]
Tulsa and Norman, Oklahoma

ABSTRACT

The methods of comparing gravity data are discussed with regard to their usefulness for petroleum exploratory work. In flat plains of slight relief any anomaly may be used almost as satisfactorily as any other. However, the "free-air" anomaly has the obvious advantage that it involves the least trouble in calculation. But in regions of considerable relief, such as mountains and dissected plateaus, the only serviceable anomalies are the *topographic* and *Bouguer* anomalies. The latter is a satisfactory, practical substitute for the former, which is difficult to compute. All the "isostatic" anomalies are unsatisfactory in rugged topography on account of their assumptions regarding subsurface density conditions, to say nothing of the great difficulty of computation. The free-air anomaly is also unfit for such terranes.

INTRODUCTION

Since pendulum gravity measurements are being used in the search for petroleum-bearing geologic structures, and since there is some difference of opinion about the most appropriate method of using the gravitational data, it is perhaps not untimely to analyze the different methods of reduction with regard to their fitness for this purpose.

The fundamental principle involved in pendulum measurements is the law of gravitation itself, namely, that every body in the universe attracts every other body, and that the attractive force between any two bodies is directly proportional to the product of their masses and

[1]Manuscript received by the editor, May 10, 1928.

[2]Geophysical Research Corporation, Box 2022.

[3]Department of Geology, University of Oklahoma.

inversely proportional to the square of the distance between them. Thus it will be seen that the earth's gravity at a given point on its surface is the sum of the separate attractions, at that point, of the separate particles composing the earth. Hence, if there is an abnormally dense body, such as a granite ridge, or a salt dome, directly beneath a given point on the earth's surface, the value of the gravity at that point will be different from the value it would have if such a body were absent.

Therefore the problem involved in the use of pendulum measurements for petroleum exploration is the detection of differences in gravity at the surface due to changes in density in the subsurface materials from place to place. From this, in turn, something of the subsurface structural conditions can be determined.

At first thought it would seem that in order to find the differences in gravity from place to place in a given region it would only be necessary to make measurements at different points and compare them directly. Since, however, there are other factors which affect gravity more than the subsurface density differences sought, all these factors must so far as practicable be eliminated. For this reason, gravity observations must be reduced, so to speak, to a common denominator, for purposes of comparison.

THEORETICAL EARTH GRAVITY

If the earth were a perfect sphere composed of concentric homogeneous shells, and if it were at rest in space, its gravity would be exactly equal at all points on its surface. Since, however, the earth is rotating about its axis and is approximately an oblate spheroid in shape, gravity is found to differ considerably in different places.

Following the work of Clairaut and others, Helmert found that on an oblate spheroid composed of concentric shells the gravity varied according to the following formula:

$$\gamma^{\circ} = g_e (1 + b_2 \sin^2 \phi + b_4 \sin^2 2\phi) \qquad (1)$$

where γ_o is the gravity at a given point on an equipotential surface w_o, g_e is the gravity at the equator on the surface w_o, ϕ is the geographic latitude of the given point, and b_2 and b_4 are coefficients. Solving for the coefficients in this formula from a large number of gravity measurements, Helmert (in 1901) derived the following formula for the gravity of the earth at sea-level:

$$\gamma^{\circ} = 978.046 (1 + 0.005302 \sin^2 \phi - 0.000007 \sin^2 2\phi) \qquad (2)$$

where γ_o is the theoretical earth-gravity at the geographic latitude ϕ.

From this formula we are able to calculate the theoretical value of gravity at sea-level at any place on the earth's surface, given only the geographic latitude ϕ (Fig. 1). Then by *observing* the value of gravity at the given point (with a pendulum) and, in turn, reducing the ob-

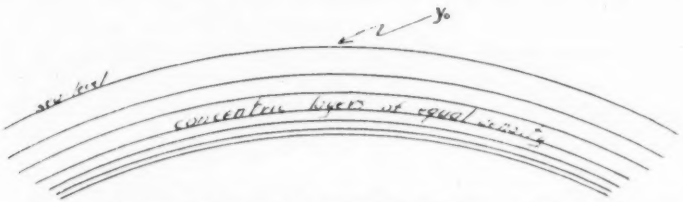

FIG. 1.—Diagram illustrating the concentric homogeneous layers, and γ_0, the theoretical gravity at sea-level, of the "theoretical" earth.

served value to sea-level, a direct comparison may be made between the *observed* and the *theoretical* values of gravity at sea-level beneath the point considered.

The result of this comparison is known as the *gravity anomaly. A gravity anomaly is defined as the observed value of gravity (reduced to sea-level) minus the theoretical value of gravity at sea-level beneath the point in question.*

$$g \text{ (observed and reduced)} - \gamma_0 \text{ (theoretical gravity)} = \text{gravity anomaly.} \qquad (3)$$

METHODS OF REDUCTION

A. NON-ISOSTATIC METHODS

There are several standard methods of reducing observed gravity to sea-level, each of which gives a different value and a different anomaly. These anomalies vary widely with the different methods of reduction; and the anomaly differences of near-by stations may or may not bear some relation to subsurface density differences between the stations. The objects of the petroleum geophysicist are, however, (1) to find an anomaly of which the variation from station to station is due mainly to a similar variation of subsurface density, and (2) to eliminate those reductions whose anomalies do not exhibit this correspondence. Another factor to be considered is the relative ease with which different methods of reduction may be applied.

Before considering in detail the different methods of reduction, it should be borne in mind that the theoretical value of gravity at a point

at sea-level is that gravity which the earth would have if it were an oblate spheroid of concentric homogeneous shells out to sea-level, and with no topography above sea-level. Hence, the anomalies are in all cases due to the uncorrected departure of the *real earth* from this *theoretical earth* with concentric homogeneous shells.

1. *The "free-air" reduction.*—The free-air reduction consists only of a correction for the height of the station above sea-level, just as though the earth's surface were at sea-level and the observations had been taken in "free air" at a height above the surface equal to the elevation of the station (Fig. 2).

FIG. 2.—Diagram illustrating the "free-air" reduction; g is the observed, or measured, value of gravity at a station above sea-level, at height h; g_o is g *reduced* to sea-level. No corrections are made for the topography of the entire earth. Shaded spots represent masses of irregular density beneath sea-level.

If we let

g = the observed value of gravity at a point above sea-level (i. e., the force which earth-gravity exerts on a mass of one gram at that point)

h = the height of the point above sea-level

g_o = the gravity at sea-level beneath the point

M = the mass of the earth

R = the radius of the earth (assuming that the earth is a perfect sphere)

K = the constant of gravitation

Then: $$g_o = \frac{KM}{R^2}$$

and $$g = \frac{KM}{(R+h)^2}$$

therefore $$g_o = \frac{g\,(R+h)^2}{R^2}$$

and $$g_o = g + \frac{2gh}{R} + \frac{gh^2}{R^2} \qquad (4)$$

Since, in the case of the earth's surface, h is always very small compared with R, the last term of equation (4) is negligible and may be dropped, leaving

$$g_o = g + \frac{2gh}{R} \tag{5}$$

The quantity $\frac{2g}{R}$ (assuming the earth to be a sphere) is a constant; hence the sea-level value of gravity becomes

$$g_o = g + kh \tag{6}$$

which may be expressed numerically as

$$g_o = g + 0.0003086\,h \tag{7}$$

where g is given in dynes of force per gram, and where h and R are given in meters.

The anomaly from this method of reduction is very seldom equal to zero. It is called the "free-air" anomaly, though it is also sometimes called the "total" anomaly. The International Geodetic Association symbol is $g_o - \gamma_o$.

In order to determine the causes of the "free-air" anomaly (why the theoretical and the observed values of gravity reduced by the free-air method are different from each other), the false assumptions must be found on which this reduction is based. It is assumed (1) that there is no rock above sea-level, and (2) that the earth is composed of concentric homogeneous shells out to sea-level. Thus, the cause of this anomaly is failure to make correction for the attraction of the topography above sea-level, and failure to recognize the departure of the outer shells of the earth from homogeneity (ocean basins and subsurface irregularities). Therefore, the part of this anomaly due to local subsurface irregularities is a very uncertain quantity.

2. *The topographic reduction.*[1]—This method consists in reducing the observed value of gravity to sea-level as in the free-air reduction; plus a correction for the gravitational effect (at the station considered) of all the topography of the earth above sea-level, assuming a uniform density; plus a correction for the density deficiency of the water in the ocean basins. It is as though all the topography of the earth were re-

[1]The "Rein-Topographisch" reduction of recent German publications.

moved and all the ocean basins were filled with material the density of which is equal to the mean surface density of the earth (Fig. 3).

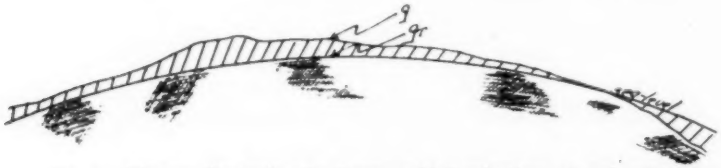

FIG. 3.—Diagram illustrating the "topographic" reduction; g is reduced to sea level as in Figure 2, and is also *corrected* for the topography of the entire earth. Shaded areas are masses of irregular density. Diagonal lines mark the part of the earth for which corrections are made by calculation.

The topographic *anomaly* is due to the departure of this leveled-off and filled-in earth from the theoretical earth of the Helmert formula. The customary symbol for it is $g_T - \gamma_o$. It is obvious that the major discrepancy between the two is due to the assumption of homogeneity in the concentric shells of the theoretical earth. It is true that the ocean basins have been filled in to meet this requirement of homogeneity, but the density irregularities in the outer part of the earth remain and produce their disturbances. The only earthly irregularities for which corrections have not been applied are the subsurface differences in rock density, and these remain to influence the topographic anomaly. Density differences near a station will exercise a predominant effect upon the gravity anomaly of that station; and the horizontal variation of this anomaly from place to place will therefore follow the horizontal variation of major subsurface structural features.

3. *The Bouguer reduction.*—The Bouguer reduction of observed gravity to sea-level, though developed long before the topographic reduction, may be thought of as a first approximation to the latter. This reduction consists of (1) the usual height correction; (2) the attraction of the stone plate between the station and sea-level on the assumption that the plate is of uniform thickness, of homogeneous density, and of infinite horizontal extent; and (3) an "orographic" correction for the departure of the surface of this plate from the postulated plane surface (Fig. 4). The International Geodetic Association symbol is $g_o - \gamma_o$.

It is evident that for work of great detail where stations are close together, as would be the case in petroleum work, the effect of distant topography and ocean basins at neighboring stations would remain practically constant. Therefore, in practical work where the

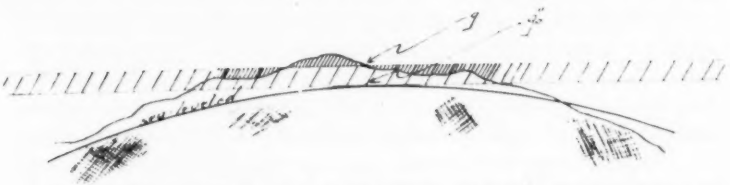

FIG. 4.—Diagram illustrating the "Bouguer" reduction. The topography is leveled to a plain, the height of the station; g is then reduced to sea-level, and the attractive effect of the flat plate of rock of thickness h is eliminated. Diagonal lines show that part for which corrections are made by calculation.

Bouguer anomaly is used, these distant effects need not be eliminated. The local anomaly variations would be due largely to local density variations, as in the case of the topographic reduction.

B. ISOSTATIC METHODS OF REDUCTION

1. *The Pratt-Hayford reduction.*—This method of reducing gravity to sea-level was worked out by Hayford on the basis of the Pratt assumption of isostasy. Pratt assumed (1) that the earth's crust has a base which is everywhere at a uniform depth below sea-level, and (2) that all vertical columns of equal area have the same mass. This is, in effect, an assumption that all the topography of the earth is due to lack in uniformity in the density of the crust. The height of the surface of any column above sea-level is inversely proportional to its density.

The Pratt-Hayford reduction consists of: (1) the usual height correction, (2) the topographic correction (the same as used in the topographic reduction previously mentioned), and (3) a correction for the assumed density distribution in the outer shell according to the Pratt hypothesis. The depth of the crustal base assumed by this hypothesis is generally taken as 113.7 kilometers (Fig. 5).

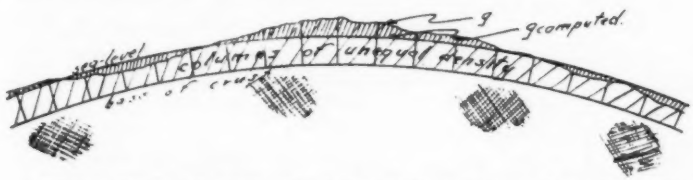

FIG. 5.—Diagram illustrating the chief Pratt-Hayford assumptions. Conventions are the same as in earlier figures.

The Pratt-Hayford isostatic anomaly is best designated by $g_I - \gamma_o$, though the symbol $(g - gc)$, (g observed minus g computed) is much used.

2. *The Airy-Heiskanen reduction.*—The Airy-Heiskanen method of reduction is identical with the Pratt-Hayford method in all respects except that the Airy assumption of crustal density distribution is used. Airy assumed (1) that the earth's crust is of different thicknesses in different places, (2) that the crustal density is everywhere the same, and (3) that the crust is so weak that its surface elevation at any place is proportional to its thickness at that place. Thus, underneath mountains the crust should protrude deeper into the subcrustal material than beneath plains; and beneath ocean basins the crust should be exceptionally thin.

This reduction consists of (1) the usual height reduction, (2) a correction for the topography of the whole earth (*vide ante*) and (3) a correction for the density distribution according to the Airy assumptions previously stated (Fig. 6).

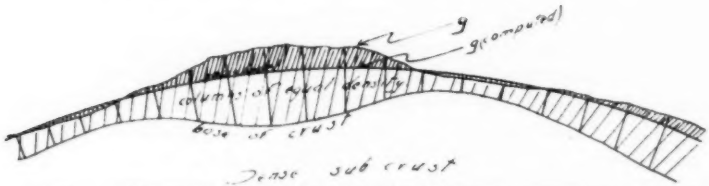

FIG. 6.—Diagram illustrating the chief Airy-Heiskanen assumptions. Conventions as before.

There is no accepted symbol for the Airy-Heiskanen isostatic anomaly. It is, as a rule, however, g (reduced) $- \gamma_0$.

Either of the foregoing isostatic anomalies represents all of the corrections for elevation of the station and for topography of the whole earth, as well as a correction for an *assumed* subsurface density arrangement. Since the computed effect of this density arrangement differs with the elevation of stations, there will always be some doubt as to whether isostatic anomaly differences are due to the *assumed* subsurface density arrangement or to the actual density arrangement.

CONCLUSION

The topographic anomaly is most closely allied to the local density variations, and is therefore most useful to the petroleum geophysicist. The objection to its use is the labor involved in its computation. Next in usefulness to this anomaly is the Bouguer anomaly, which for detail work is almost as good. It is computed with greater ease than the topographic anomaly, though it still involves considerable care in the use of

topographic maps and the computation of the topographic gravitational effects. The isostatic anomalies are less satisfactory because of their uncertain assumptions about subsurface density conditions. Besides, these anomalies are the most difficult of all to compute. According to Hayford (20), a trained computer, equipped with the proper tables and maps, was able to compute one anomaly in 17 hours. In rugged topography, where the relief is more than 200 or 300 feet, the free-air anomaly is least satisfactory of all from the standpoint of accuracy, though it is the easiest of all anomalies to compute. This is because the gravitational effect of the adjacent topography is not eliminated.

On surfaces of slight relief all the corrections for any one kind of anomaly at near-by stations are substantially equal. Consequently the anomaly differences correspond closely with the differences in the measured value of gravity from station to station. Therefore, in this kind of topography any anomaly might be used for detailed exploratory work almost as satisfactorily as any other anomaly. Here, the free-air anomaly may obviously be used with least trouble, since it involves only the height correction. But in topography of considerable relief, such as mountains, dissected plateaus, and dissected plains where the relief is more than a few hundred feet, the only satisfactory anomalies are the topographic and Bouguer anomalies. The latter is a practical substitute for the former. The isostatic anomalies are unsatisfactory on account of their assumptions regarding subsurface density, to say nothing of the great difficulty of computation. The free-air anomaly is totally unfit for such terranes.

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FACTORS AFFECTING THE COLOR OF SEDIMENTARY ROCKS[1]

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INTRODUCTION

The color of sedimentary rocks differs with the materials of which they are composed, the class of coloring agents and their proportions, and the mechanical and chemical conditions in which such agents occur. These in turn are influenced by the source of the sediments, their transportation, the mechanical and climatic conditions under which the beds were deposited, and chemical changes in the coloring agents after deposition. In fact, many factors enter into the ultimate color of sedimentary rocks. Iron and carbonaceous material in their different phases are responsible for most of the coloration, and this paper will be devoted largely to a discussion of the conditions affecting these two agents, with a brief mention of rocks owing their color to primary or secondary minerals. The article is in three parts, summarized in the abstracts.

ACKNOWLEDGMENTS

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I

SOURCES AND MECHANICAL AND CHEMICAL NATURE OF THE COLORING AGENTS

ABSTRACT

Iron and carbonaceous material are the two most important coloring agents in sedimentary rocks. Iron in the form of limonite ($2\ Fe_2O_3 \cdot H_2O$) colors sediments

[1]Manuscript received by the editor, May 4, 1928.

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yellow to brown. Limonite may be dehydrated to goethite ($Fe_2O_3 \cdot H_2O$) which similarly colors sediments, but with more of an orange tinge. Further dehydration gives turgite ($2\ Fe_2O_3 \cdot H_2O$) with an Indian-red streak. On complete dehydration, hematite (Fe_2O_3) is formed. It colors sediments red. Mixtures of limonite and hematite give orange shades. Purple colors are probably due to a mixture of green ferrous-ferric silicates and red hematite.

An examination of analyses of slates and shales shows that in red slate there is several times as much ferric iron (Fe_2O_3) as ferrous iron (FeO). In purple slates, the ratio is about half that in the red. In green slates and shales, ferrous iron predominates to a marked degree. In some green shales, finely divided glauconite is the coloring agent; in others, the color is due to ferrous-ferric silicates. Green shades, as well as blue, denote conditions of deposition under reducing circumstances.

Carbonaceous material occurs as the hydrocarbons (C_n)(H_{2n+2}), or as the carbohydrates $(C)^x(H_2O)_y$. They impart gray, brown, or black shades to sediments.

Truly blue shales are uncommon. Most shales classed as such are blue or blue-gray when wet, and gray when dry. The blue shade is due to the presence of water and probably air in the pores of the shale, which reflect the blue rays of light. Such blue shales as retain this tinge when dried, owe their color to hydrous ferrous-ferric compounds, probably silicates. The bulk of the iron in most blue-gray shales, and to a less extent in green shales, is in the form of $FeCO_3$, which is colorless.

COLOR DUE TO MINERALS IN THE ROCK[1]

[1]P. E. Raymond, manuscript.

If it were not for the coloring agents, iron and carbon, sedimentary rocks would tend to be light in color, as quartz and calcite are their most common minerals. In fragments, both of these are dominantly white. Some deposits of nearly pure quartz sand seen along river beds and in the older formations approach whiteness. This is illustrated by beds of white sand in the Catahoula formation of north-central Louisiana, and sand in the basal Trinity of Texas.

While quartz is the predominant mineral in many sandstones and shales, their ground mass may consist of finely divided silt or clay. If this material is derived from areas where disintegration rather than rock decay has taken place, and has not been oxidized during transportation and deposition, its color is apt to be neutral gray. It is a mixture of finely powdered minerals which are lighter in tone in the powdered than in the massive condition.

Arkoses may be yellow, pink, or flesh-colored, because of the feldspar which they contain. A yellow tone may be imparted to sandstones which contain much undecomposed feldspar. Some sands may contain sufficient magnetite, augite, ilmenite, or other dark mineral, to give a dark or even black color, though these minerals are not, as a rule, sufficiently concentrated to form the main coloring agents in rocks. They give a speckled effect to some layers. A greenish cast in some rocks is caused by a large amount of epidote. Muscovite gives a silvery appearance to some sandstones.

Rocks composed of pure $CaCO_3$, such as chalk and limestone, are white. Generally, there is sufficient carbon or iron in limestones to tint them gray, yellow, brown, or red. Calcium carbonate in the unleached state, when mixed with clays and sands, tends to lighten their color.

THE ORIGIN OF COLORING AGENTS

Iron occurs almost universally in igneous rocks from which the sedimentary rocks are derived. In the more acidic rocks, such as the granites and syenites, it occurs as the accessory minerals magnetite, ilmenite, and pyrite; and in the iron silicates, such as biotite, hornblende and pyroxene. In the more basic rocks, such as the diorites and gabbros, iron occurs not only in the accessory minerals, but in greater volume in the iron silicates, especially the pyroxenes. If such rocks are subjected to conditions of decay for long periods, most of the iron in the form of magnetite, ilmenite, and pyrite will be oxidized to a ferric state, the silicates will be decomposed, and their iron changed to ferric oxide. Such conditions prevail in warm, moist climates, where rock transportation is slow. The iron in such rocks may be largely oxidized before transportation has removed them from their original source.

Where the igneous rocks are subjected to disintegration rather than decomposition, the iron will be oxidized to a much less extent, and may even be unchanged. The iron silicates may still be fresh or but slightly altered when their transportation begins. Rocks in high, dry areas are favorably situated for rock disintegration, and their particles may be carried long distances by the wind or by infrequent rains, with little chemical decomposition. The colors of such deposits will tend to be light, especially in regions where there are many acidic igneous rocks with light-colored feldspars. Grays, buffs, pinks, or yellows will be common. Disintegration in areas of more basic igneous rocks will give darker-colored residual soils and local deposits, due to the greater amount of dark minerals in the original rocks.

Organic material in nature is formed by living organisms such as plants and animals. Plants contribute more carbonaceous material to the sediment than do animals, due to their greater abundance and to the fact that the cellulose of woody material is particularly resistant to the action of bacteria and oxidation. Organic material consists of more or less complex compounds of carbon and hydrogen. It may either be in the form of $(C_n)(H_{2n+2})$, the hydrocarbons; or of $(C)_x(H_2O)y$, the carbohydrates.

OXIDATION

The oxidation of iron and carbonaceous material is so important that it will be well to point out the main features of the process.

The factors favoring oxidation are heat and moisture. The free oxygen of the air combines with carbon or iron more readily at high temperatures than at low. Oxidation takes place much more readily in the presence of water vapor than it does in dry air. The explanation of this fact is uncertain. Dr. Boughton, of the Department of Chemistry, Harvard University, believes that water vapor decomposes the molecules of the oxygen of the air into atoms which are more active chemically than the molecules of dry oxygen.[1] However, oxidation takes place under water less readily than in air. The explanation of this probably lies in the fact that while water can absorb several times its volume of oxygen, it can absorb only 0.02 of 1 per cent by weight. As the oxygen is used up in combining with materials in the process of oxidation, it is less readily replaced in water than in air. This is especially true of quiet, or stagnant water.

Destruction by bacteria goes hand in hand with that by oxidation in the decay of organic material. It, also, is favored by heat and moisture, and proceeds less rapidly under water, due to the lesser amount of oxygen to supply the organisms.

IRON IN SEDIMENTARY ROCKS

When rain water, which contains both O and CO_2, acts on igneous rocks, it removes the more soluble minerals, liberates colloidal silica, and forms carbonates of lime, iron, magnesia, and the alkalies. The feldspars are then hydrated into kaolin, and if the rock decomposition is completed in warm, moist climates, laterite results. The iron carbonate which is formed from the ferrous silicate is almost instantly oxidized, forming a visible rusty coating of ferric hydroxide (limonite or goethite) which stains the grains of the residual rock yellow to brown or which may float some distance away as a thin scum, before being deposited.[2] The ferrous oxide (FeO) derived from the iron in the silicates combines to form the carbonates, as follows:

$$FeO + CO_2 = FeCO_3$$

[1]Oral communication to the writer.

[2]F. W. Clark, "Data of Geochemistry," *U. S. Geol. Survey Bull.* 770, 1924, p. 484.

The change from ferrous carbonate to limonite might proceed according to the following equations:[1]

$$FeCO_3 + H_2O = Fe(OH)_2 + CO_2$$

$$4\,Fe(OH)_2 + 2\,O = 2\,Fe_2O_3 \cdot 3\,H_2O + H_2O$$

In case there is an excess of CO_2 in the water, the ferrous carbonate is readily soluble and is carried away to points where this excess CO_2 is removed before being oxidized to limonite. Ferrous carbonate ranges from very light to dark brown when crystallized as the iron ore, siderite. When formed in the laboratory, it is apple-green in color, flocculent, and settles slowly. In nature, the iron carbonate represents a transition state of the iron, and is not a coloring agent, due to the fact that it is readily soluble in waters containing CO_2, and colorless when in solution.

Limonite ($2\,Fe_2O_3 \cdot 3\,H_2O$) is insoluble in water and is one of the most common coloring agents in sedimentary rocks. It is yellow to dark brown or nearly black, with a yellowish-brown streak. Limonite may be dehydrated by heat and dryness to form goethite ($Fe_2O_3 \cdot H_2O$), which is yellowish-brown to dark brown, with an orange-yellowish brown streak. This may be still further dehydrated to turgite ($2\,Fe_2O_3 \cdot H_2O$), which is reddish-black to black, with an Indian-red streak. On complete dehydration, hematite (Fe_2O_3) is formed. This oxide is red to reddish-brown or black, with a light to dark Indian-red streak.

In the zone of weathering the oxidation of pyrite, which is brass-color to dark brown when tarnished, with a greenish- to brownish-black streak, changes the sulphide to the soluble sulphate, liberating H_2S according to the equation:[2]

$$FeS + 3\,O + H_2O = FeSO_4 + H_2S$$

and these in turn to limonite, as follows:

$$4\,FeSO_4 + 2\,O + 7\,H_2O = 2\,Fe_2O_3 \cdot 3\,H_2O + 4\,H_2SO_4$$

In many marine shales there are finely divided particles of pyrite which in this minutely divided form are black. Upon exposure, the pyrite is oxidized to limonite, giving the weathered outcrop a yellow or brown stain; and, when dehydrated, a reddish tinge.

The streak of these minerals has been mentioned because the color of a mineral in the form of films around the grains of a rock—for instance, a sandstone—corresponds more nearly to that of the streak than to the color of the mineral in massive form.

[1] W. H. Twenhofel, *Treatise on Sedimentation*, 1926, p. 320.

[2] *Idem.*

Of the iron oxides mentioned which act as coloring agents in sedimentary rocks, limonite and hematite are the most common. The former colors sediments yellow, brown, and possibly orange-yellow; the latter, shades of red, including pink. Orange is due to a mixture of limonite and hematite. The extent to which goethite and turgite act as coloring agents is not known. Probably in many cases goethite is mixed in with limonite, and turgite with hematite. Judged by its streak, goethite should give about the same color as limonite, with more of an orange tinge, while turgite should give a darker red than hematite. Experiments made by Posnjak and Merwin[1] on the dehydration and specific gravities of iron oxides indicate that most limonite is really goethite with adsorbed and capillary water, and that turgite probably represents solid solutions of goethite and hematite with inclosed and adsorbed water. For the practical purposes of this paper, however, the names of the oxides listed by Dana and others will be retained.

Iron as limonite or hematite forms thin films coating the grains of sandstones and shales. Also, it occurs in fine particles in the matrix or cementing material. Russell[2] first mentioned this in connection with the coloring matter in sandstones of the Newark series. Tomlinson,[3] after a microscopic examination of thin sections of Newark sediments from Virginia, states that the ferruginous matter exists both as a coating on the sand grains and as part of the cement between them. He also quotes Richardson, who made a microscopical examination of thin sections from the Spearfish formation of the Black Hills. Richardson[4] says: "Amorphous red pigment is prominent in the slides....it irregularly coats and spots the minerals and forms the chief interstitial substance."

In addition to the quantity of the iron, its state of subdivision is very important. Hematite may be dark in massive form, but have a brilliant red color in its finely divided state. Minute particles of it may be distributed through an entire rock, thereby increasing its efficiency as a coloring agent. Tomlinson[5] brings out the fact that in our western Red-beds, the fine-grained strata are more deeply colored than the coarse,

[1]Eugen Posnjak and H. E. Merwin, "The Hydrated Ferric Oxides," *Amer. Jour. Sci.*, Vol. 47 (1919), pp. 311-48.

[2]I. C. Russell, "Subaerial Decay of Rocks," *U. S. Geol. Survey Bull. 52*, 1889.

[3]C. W. Tomlinson, "The Origin of Red Beds," *Jour. Geol.*, Vol. 24 (1916), p. 165.

[4]G. B. Richardson, "The Upper Red Beds of the Black Hills," *Jour. Geol.*, Vol. 2, (1903), pp. 365-93.

[5]C. W. Tomlinson, *op. cit.*, p. 158.

and mentions that this holds true in many other Red-bed sections. The following figures from Clarke,[1] quoted also by Tomlinson, show a greater concentration of iron in shales than in sandstones.

TABLE I

	Per Cent Fe_2O_3	*Per Cent* FeO	*Organic* C
Composite analysis of 78 shales	4.03	2.46	.81
Composite analysis of 253 sandstones	1.08	.30	....

CARBON IN SEDIMENTARY ROCKS

Carbon is black, and in nature it gives gray, brown, or black hues according to its concentration. As we have seen, organic material in nature is in the form of the hydrocarbons $(C_n)(H_{2n+2})$ and the carbohydrates $(C)_x(H_2O)_y$. By oxidation it is converted into carbonic acid and water. The simpler equations are

$$C + O_2 = CO_2$$

and $C_6H_{10}O_5$ (cellulose) $+ 12\,O = 6\,CO_2 + 5\,H_2O$

The action of bacteria plays an important part in the decay of organic matter, preparing the way for and assisting in its oxidation.

Deposits resulting from decaying organic tissues of aquatic animals and plants in quiet places on the sea bottom or in fresh-water lakes and ponds are especially rich in hydrocarbons.[2] They have a higher fat and protein content than those formed by the decay of land and swamp plants. Carbonaceous deposits resulting from the latter are high in carbohydrates or cellulose material. In the first case, oxidation and bacterial action have been retarded by the small amount of oxygen in the quiet waters; in the second case, oxidation has progressed further, leaving mainly the more resistant compounds of carbon.

The hydrocarbons form the greater part of the coloring matter in the brown and black shales from which oil may be derived, while the carbohydrates are responsible for the brown and black colors of coals and lignites.

When organic material decays, colloidal substances having feebly acidic properties, and known as humic, crenic, and ulmic acids, are formed.[3] These may act directly on the oxides of iron to reduce them to

[1] F. W. Clarke, *op. cit.*, p. 30.

[2] A. W. Grabau, *Principles of Stratigraphy*, 1913, p. 478.

[3] F. W. Clarke, *ibid.*, p. 110.

$FeCO_3$, or, if carried away by percolating waters, and brought into contact with oxides, they may reverse the oxidation which has already taken place, and reduce ferric to ferrous compounds, and sulphates to sulphides. Carbonaceous material, either directly through its decay or by means of the organic acids mentioned previously, is a great factor in nature in reducing ferric to ferrous iron. Hematite would be reduced according to the following equation:

$$2\ Fe_2O_3 + C = 4\ FeO + CO_2$$

$FeO + CO_2 = FeCO_3$, which is soluble in water containing CO_2

The hydroxide, limonite, might be reduced to the soluble carbonate as follows:[1]

$$2\ Fe_2O_3 + 3\ H_2O + C = 4\ FeO + CO_2 + 3\ H_2O$$

$$4\ FeO + 4\ CO_2 = 4\ FeCO_3$$

The $FeCO_3$ remains in solution until the excess of CO_2 is removed, when it is again oxidized to the insoluble ferric hydroxide.

TRANSPORTATION OF IRON AND CARBON

For the most part, iron is transported by rivers, in the form of minute particles of limonite, hematite, pyrite, and magnetite, as mechanical sediments. Rivers which flow through regions of basic igneous rocks may carry much iron as pieces and fragments of the ferruginous silicates.

Some transportation of iron in nature is undoubtedly due to waters carrying away $FeCO_3$ and organic compounds of iron. However, $FeCO_3$ is unstable and readily oxidizes to limonite when the excess CO_2 is removed. An examination of the analyses of the river waters of North America discloses the fact that they carry only a trace to a few parts per million of iron in the dissolved form.[2] Part of the iron in river waters is in the form of organic compounds. Iron is found in many spring waters, but is largely deposited at the point of escape.

Carbonaceous material is transported by rivers as mechanical sediments, and also to a considerable extent probably as colloidal substances which are dissolved in the water. The extent to which organic material in this form is carried by river waters is suggested by the following figures:

[1] W. H. Twenhofel, *op. cit.*, p. 332.

[2] F. W. Clarke, *op. cit.*, pp. 73-94.

TABLE II

PERCENTAGE OF ORGANIC MATTER IN THE DISSOLVED SOLIDS OF RIVER WATERS[1]

Maumee	4.55
James	4.14
Hudson	11.42
Delaware	16.00
Amazon	15.03
Uruguay	59.90
Plata	49.59

The foregoing figures indicate that waters flowing through tropical swamps carry the largest percentage of organic material.

COLORS OF SEDIMENTARY ROCKS

Grabau[2] states:

The color of clastic rocks depends to a very large degree upon the states of oxidation of its iron content, on the absence or abundance of carbon. A low state of oxidation gives colors ranging from green to blue, while the higher states of oxidation are marked by yellow, orange, brown, or red colors. According to the carbon content, the color may vary from white, when no carbon is present, to various shades of gray to black. Abundant carbon in the strata will prevent oxidation of the iron and will reduce the higher oxides to the lower. Lack of carbon favors high oxidation.

In a preceding section, it was stated that limonite and goethite color sediments yellow to brown and orange-yellow; hematite, including turgite, colors them orange, purple, and various shades of red. With reference to blue or green hues in sedimentary rocks, there are differences of opinion as to the coloring agents. The following analyses of slates and shales are pertinent:

TABLE III

ANALYSIS OF ROOFING SLATES[3]

By F. Hillebrand, U. S. Geol. Survey Laboratory.

A. Sea-green slate *C*. Black slate *E*. Green slate
B. Purple slate *D*. Red slate *F*. Black slate

	A	*B*	*C*	*D*	*E*	*F*
Fe_2O_3	.81	5.16	.52	5.36	3.48	1.67
FeO	4.71	2.54	4.88	1.20	1.42	3.23
C	....	....	.46	....	....	.59

[1]F. W. Clarke, *op. cit.*, p. 110.

[2]A. W. Grabau, *op. cit.*, p. 620.

[3]F. W. Clarke, *ibid.*, p. 554.

Tomlinson[1] shows the following analyses taken from Dale.[2]

TABLE IV

Average of the analyses of:	*Per Cent*				
	Fe_2O_3	*FeO*	*Net Fe*	*Ratio Fe''':Fe''*	*Free Carbon*
5 red slates	5.26	1.21	4.62	3.91:1.00	(No free carbon in any of the red or purple slates)
3 purple slates ...	5.30	2.15	5.38	2.22:1.00	
8 green slates	1.35	5.21	4.99	0.232:1.00	Trace

The following analyses were made by the Fort Worth Laboratories on four samples of shale from the Permian Red-beds of western Texas, furnished by the writer. The green shales immediately underlie the red.

TABLE V

Location		*Per Cent*	
		Fe_2O_3	*FeO*
Jones County, Texas, 1½ miles NE. of Trent	Red shale.....	5.15	1.28[3]
	Bright green shale.....	1.71	1.28
Coke County, Texas, 2 miles SE. of Robert Lee	Red shale.....	6.00	1.28
	Olive-green shale.....	.29	1.02

BLACK SLATES

The analyses of black slates in Tables I and II show fixed carbon, while those of the other slates do not. In the black slates the greater part of the iron has been reduced to its ferrous state (*FeO*). The black color is due to carbonaceous material.

RED SLATES AND SHALES

An examination of the figures in all the foregoing tables shows that in the red slates and shales there is several times as much ferric oxide as ferrous; the average ratio being 4.1:1. The red color is due to hematite (Fe_2O_3), or possibly to turgite ($2\,Fe_2O_3 \cdot H_2O$). In the purple slates the ratio is still large, but less than in the red, the average being 2.16:1. The purple color in some slates is due to a mixture of red ferric iron and

[1] C. W. Tomlinson, *op. cit.*, p. 160.

[2] T. N. Dale, "The Slate Belt of Eastern New York and Western Vermont," *U. S. Geol. Survey Ann. Rept. No. 19*, 1899, Pt. 3, pp. 232, 246-53, 257, 264; and "The Roofing Slates of the United States," *U. S. Geol. Survey Bull. 275*, 1905, pp. 34-36.

[3] On account of the percentage of *FeO* being identical (1.28) in the first three samples, the writer had the analyses repeated, with the same results.

bluish-green chlorite.[1] In shales it is probably due to a mixture of red ferric iron and bluish-green ferrous-ferric silicates. Green shales commonly weather purple.

GREEN SLATES AND SHALES

In the sea-green slate *A*, Table III, the quantity of FeO is nearly six times that of Fe_2O_3, while in the green slate *E*, the Fe_2O_3 is 2.45 times that of the FeO. However, in the green slates in Table IV, the amount of ferrous oxide is 3.86 times that of the ferric, and each of the analyses of the eight green slates from which this average was made showed a preponderance of FeO over Fe_2O_3. In Table V, the bright green shale contained 1.36 times as much ferric as ferrous oxide, while the olive-green shale contained 3.52 times as much ferrous as ferric. To sum up, nine of the eleven green slates and shales analyzed contained a decided preponderance of FeO over Fe_2O_3. In the other two cases, the Fe_2O_3 predominated, but there was also a comparatively large percentage of FeO present. The iron is probably in the form of a green ferrous-ferric silicate. Fash,[2] of the Fort Worth Laboratories, thinks that this is the case, but stated that it would be difficult to determine the fact from chemical analyses. The shale itself is made up of aluminous silicates and silica, which would be difficult to separate in an analysis from the silica of the green pigment. The green color can not be due to glauconite, which is a ferric silicate, as, in the nine shales and slates mentioned, the proportion of ferrous iron is entirely too high. Further, the two green shales included in Table V are from the Permian Red-beds of western Texas. Miss Hedwig Kniker,[3] of San Angelo, Texas, has examined under the microscope many sections of green shale from these Permian beds, but has found no glauconite in any of them.

While not present in all green shales and sands, glauconite is an important green coloring agent in many. It is a hydrated silicate of ferric iron and potassium, with the formula $Fe_2KSi_3O_6 \cdot aq$.[4] Though called a ferric silicate, the following analyses show that part of the iron is in the ferrous state.

[1] T. N. Dale and others, "Slate in the United States," *U. S. Geol. Survey Bull. 586*, 1914, p. 143.

[2] R. H. Fash, vice-president, Fort Worth Laboratories. Personal communication to the writer.

[3] Personal communication to the writer.

[4] F. W. Clarke, *op. cit.*, p. 521.

TABLE VI

ANALYSES OF GLAUCONITE[1]

A. Glauconite from Woodburn, Antrim, Ireland.
B. Glauconite from Cretaceous sandstone, Paid, Government Saratoff, Russia.
C. Glauconite from greensand marl, Hanover County, Virginia.
D. Oceanic glauconite; mean of four analyses.
E. Glauconite, Monte Brione, Lake Garda, Italy.

	A	*B*	*C*	*D*	*E*
Fe_2O_3	16.81	23.43	15.16	21.46	19.13
FeO	10.17	1.32	8.33	1.58	3.95
H_2O	6.19	4.93	10.32	5.96	6.32
Organic	.....	.....	.....	.....	

The writer has seen sands in the Navarro and Midway formations in which the green color is entirely due to glauconite. Mrs. Esther Applin,[2] of Houston, Texas, states that microscopic examination of most green shales in the Miocene and Oligocene of Texas shows glauconite to be present. The coloring agent in these shales is probably due to finely divided particles of glauconite. Twenhofel states:[3]

> In the marine sediments, the green hydrous potassium silicate, glauconite, gives color to the green sands and green muds which are peculiar to the slightly reducing areas of the continental shelves and slopes.

From these facts, it is evident that the green color in some strata may be due to the presence of iron in the ferrous state, probably in the form of a ferrous-ferric silicate, while in others it is due to the presence of glauconite, a ferric-ferrous silicate. In both cases, part of the ferric oxides has been reduced to the ferrous state (*FeO*).

That green shales denote a condition of reduction of part or most of the ferric iron is indicated in the process by which glauconite is formed, which will be mentioned later. It is further shown by the formation of green spots in red shales. In this connection, Bowles states:

> From microscopical and chemical work done by Dale and Hillebrand, it appears that the pale green spots in red and purple shales are due to chemical changes caused by the decay of organisms embedded in the clays from which the slates are formed.[4]

Muds and clays contain aluminous silicates, silica, and iron hydroxides in the colloidal form. In shale, as *FeO* is liberated by the action of organic matter or organic acids, colloidal silica is freed by the action of

[1] F. W. Clarke, *op. cit.*, p. 522.

[2] Personal communication to the writer.

[3] W. H. Twenhofel, *op. cit.*, p. 545.

[4] Oliver Bowles, "The Technology of Slate," *U. S. Bureau of Mines*, 1922, p. 13.

such acids on aluminous silicates. In both cases, the colloidal silica would furnish the acid radical to form ferrous-ferric silicates.

"BLUE" SHALES

Table VII shows analyses of marine clays, made by G. Steiger in the laboratory of the U. S. Geological Survey.[1]

TABLE VII

A. Composite of 51 samples of the "red clays."
B. Composite of 52 samples of terrigenous clays; namely, 4 green muds and 48 "blue" muds.

	A	*B*
Fe_2O_3	8.66	5.07
FeO	.84	2.30
C	.....	1.69

The following analyses were made by the Fort Worth Laboratories on samples of "blue" shale gathered by the writer.

TABLE VIII

A. Sample from drilling well of R. G. Gillespie's Newton No. 1, Crosscut field, Brown County, Texas; depth, 100 feet—; age, Pennsylvanian.
B. Sample from R. G. Gillespie's Henson No. 15, Crosscut field, Brown County, Texas; depth, 250 feet—; age, Pennsylvanian.
C. Sample from Shubert Drilling Company's Schofield No. 1, Cooke County, Texas; depth, 1,200 feet; age, Pennsylvanian.
D. Sample from Vacuum Oil Company's Kitchens No. 1, Cooke County, Texas; depth, 3,538 feet; age, Pennsylvanian.

	A	*B*	*C*	*D*
Fe_2O_3	.00	.00	.29	.58
FeO	4.60	6.65	4.09	4.35

A study of Table VII shows that there is nearly ten times as much Fe_2O_3 as FeO in the "red clays." No carbon was present. These are typical red clays from the oceanic depths. In the composite of the 48 blue and 4 green muds, there was only a little more than two and a half times as much ferric oxide as ferrous. The carbon present was 1.69 per cent. These blue muds are at present being laid down on the continental shelf and slope, and, as will be mentioned later, are typical of the source of our "blue" shales.

An examination of Table VIII shows that in the samples of Pennsylvanian "blue" shale analyzed, the percentage of Fe_2O_3 is either zero, or very small, all or most of the iron being in the ferrous state. Also the

[1] F. W. Clarke, *op. cit*,. p. 518.

total iron content is only a little more than half of that in the blue muds mentioned in Table VII. This suggests that the process of reduction of the iron by carbonaceous material in the muds, and its removal as a soluble ferrous carbonate, continues for some time after the muds are deposited, possibly during the early stages of their solidification. It would take the analyses of a great many more blue shales to confirm this. Carbonaceous material is present in blue-gray and gray shales and is the logical agent to reduce the Fe_2O_3 to FeO; the resulting product being siderite ($FeCO_3$). This is present, in these shales as well as in green shales to a less extent, not by itself, but probably as an isomorphous mixture of the carbonates of iron, lime, and magnesium, as suggested by Dale.[1] Iron is also commonly present in blue-gray and gray and green shales as scattered particles of pyrite or marcasite (FeS).

With reference to oceanic blue muds, Twenhofel[2] remarks:

> Blue muds and silts are found in the deeper waters adjacent to land and in all enclosed or partially enclosed bodies of water. The materials of which they are composed are very complex, and are the products of decomposition and disintegration together with more or less organic matter. If the organic matter is of large quantity, the muds and silts become black. At the surface, the color is apt to be reddish or brownish, but beneath the surface it is slate-colored. The blue-gray color is due to organic matter and finely-divided ferrous sulphide.

Further, he adds:

> The oceanic blue muds and certain other deposits made under water in the absence of a sufficient supply of oxygen owe their somber hues partly to the presence of the black amorphous sulphide, hydrotroilite. In the corresponding indurated equivalents, however, this material is not found. Being relatively unstable, it tends to crystallize later in the more permanent form of marcasite or pyrite.[3]

Again,[4] he refers to this "gray (often called 'blue') mud," indicating his doubt as to its bluish tinge. He further suggests that blue-gray and gray shales denote a greater reducing condition of deposition than green shales, since as a rule they contain more carbonaceous material.[5]

[1] T. N. Dale and others, *op. cit.*, p. 56.

[2] W. H. Twenhofel, *op. cit.*, 1926, p. 196.

[3] *Ibid.*, p. 544.

[4] *Ibid.*, p. 548.

[5] *Ibid.*, p. 197.

In many of the logs of wells drilled for oil in different sections of Texas, blue shales are recorded. However, when the writer began to look for blue shales, he was disappointed. He collected shales from wells being drilled into the Pennsylvanian formation in Eastland, Brown, and Cooke counties, Texas, selecting the bit samples which appeared bluest. These were unquestionably a dark blue when wet, but upon drying, they became gray or dark gray. The same phenomenon was observed on outcrops of Pennsylvanian shales, and shales of Midway (Tertiary) and Navarro (Cretaceous) age. In addition to turning gray upon drying, the weathered outcrops of such blue-gray shales were in many places streaked yellow or orange, due to the oxidation of their contained ferrous carbonates and minute particles of pyrite to limonite.

Blue clays are recorded in many wells drilled in the Gulf Coast of Texas. In this connection the writer consulted with Mrs. Applin and Marcus Hanna, who have examined many specimens under the microscope. The former stated that practically all the samples of "blue" shale which she had examined were gray, or at best, bluish-gray, when dried. However, she remembered a few samples from the Oligocene which were turquoise blue or blue-green when dried; but these were exceptional. Mr. Hanna had seen wet blue and bluish-gray shales, but he stated that they were gray after drying. Both Mrs. Applin and Mr. Hanna remarked that pyrite was common in blue-gray shales.

The color of an object is determined by the wave length of the rays of light which it reflects or transmits to the eye either by a contained pigment, or, in rarer cases, by a structural arrangement. In red, purple, or yellow shales, finely divided or amorphous hematite or limonite forms the pigment; in green shales, ferric-ferrous or ferrous-ferric silicates. Regardless of whether wet or dry, these pigments reflect the rays of light of such lengths as to give an impression to the eye of red, purple, yellow, or green. We have seen that "blue" shales are blue or bluish-gray when wet and gray when dry. The blue tinge is probably caused by the presence of included water and possibly air. The body of such a shale is gray, since it is itself composed largely of light-colored particles and grains of aluminous silicates and quartz mixed with carbonaceous material. When its minute pores are filled with particles of water or air, these reflect the blue rays, making the color of the shale blue or bluish-gray. Illustrating the reflection of the blue rays by a structural arrangement, Bancroft[1] states

[1]W. D. Bancroft, *Applied Colloidal Chemistry*, 1921, pp. 201-2.

that there is no blue pigment in the feathers of any birds, with the exception of those of metallic luster. He remarks:

> This means the blue of the kingfisher....and the bluebird is not due to blue pigment; but is a structural color. The only pigment in the blue feathers of these birds is a dark brown one which seems to serve as a background, just as in the case of a blue eye. The best explanation of the blue feather is that the horny matter is filled with an enormous amount of air bubbles which scatter blue light...The blue of feathers is due to the scattering of light by bubbles of gas, air suspended in a solid medium. The blue color of the sky is due to the scattering of light by particles of liquid or solid in a gas—the air.

In red, yellow, or green shales, when wet, the blue rays are probably reflected by the inclosed moisture or air, but the red, yellow, or green rays reflected by the pigments in the shales themselves overcome the bluish rays. In the case of gray shales, the blue rays are registered by the eye, as gray is more nearly neutral.

The writer has seen a few shales which retained their blue color when dried. These were, as a rule, largely calcareous. He obtained samples from 2,845 to 2,915 feet from the Moutray Oil Company's Jones No. 1, in Dickens County, Texas, which remained blue when dry. They were of Permian age and contained considerable lime.

MacCarthy,[1] from experiments on the oxidation of ferrous compounds, the reduction of ferric compounds, and the dehydration of blue iron silicates, phosphates, and aluminates, reached the conclusion that the blue colors in shales and slates were due only to hydrated ferrous-ferric iron. He further noticed that the more hydrous green and blue ferrous-ferric compounds were very unstable, losing their colors on exposure to air. He ascribed this to rapid oxidation.

It is not unreasonable to believe that the blue colors of some clays and shales are due to hydrous ferrous-ferric compounds. The analyses of blue muds and shales in Tables VII and VIII show both types of iron present. Hydrous ferrous-ferric minerals such as vivianite, vesuvianite, and glaucophane, have different shades of blue, as pointed out by MacCarthy. However, the writer does not subscribe to this explanation, except where the clays and shales remain blue upon drying. The change in color from blue to gray in shales which he collected took place as rapidly as the samples were dried, in some samples in an hour or two at normal temperatures. It is hard to believe that this change in color was due to the oxidation of blue hydrous ferrous-ferric compounds, probably silicates, as mentioned under green shales. It took

[1] G. R. MacCarthy, "Colors Produced by Iron in Minerals and the Sediments," *Amer. Jour. of Science*, Vol. 12 (1926), pp. 17-36.

place too quickly, and indicated that the water was simply adsorbed by the shale, and was not in chemical combination with the iron.

To sum up, the blue colors of some clays and shales are due to their contained hydrous ferrous-ferric compounds. Most of such so-called blue shales are really blue only when wet, and are gray when dry.

II

CLIMATIC EFFECTS ON THE COLOR OF CONTINENTAL CLASTICS, RED-BEDS

ABSTRACT

In cold, wet climates, carbonaceous material accumulates and tends to color the land and surrounding oceanic deposits gray or black. In hot, moist climates, oxidation is rapid and many bacteria are present. Dead vegetation, except where deposited under water, tends to be destroyed. The iron in the residual soils is thoroughly oxidized and dehydrated to form red laterite. Streams from such areas make red land deposits and carry red loads to the ocean, but, when deposited there, the hematite is reduced by organic matter, and such oceanic deposits are gray beneath their surface.

The characteristics of intermittently rainy climates are those of extremely moist climates modified. In temperate climates of moderate rainfall, such as characterize the eastern half of the United States, there is generally sufficient humus in the soils and stream deposits to color them gray, brown, or black. The colder parts of the year tend to preserve this humus. Where there is more iron in the parent igneous or sedimentary rocks than the amount of the decaying organic material present can reduce, this excess iron colors the soils and stream deposits. In the northern states, more of the iron is in the form of limonite and goethite, and yellow and brown shades are prevalent. Farther south, the sun's rays are hotter and red shades due to turgite and hematite are common.

In semiarid climates, the soils and alluvium tend to be light-colored, though less so than in arid climates.

In arid climates, oxidation is not active, due to the absence of water vapor in the air, though there is more oxidation in hot, arid climates than in cold. Disintegration rather than decomposition takes place, and the colors of the sediments are influenced to a large extent by the colors of the minerals derived from the parent rocks. Such deposits are generally light-colored, due to the presence of quartz, feldspar, and gray silicates. Much of the iron is in the unoxidized form of magnetite, pyrite, or ilmenite. Carbonaceous material is scarce. Grays, light browns, yellow, buffs, and pinks predominate. Some aeolian deposits in hot, arid regions are red, though generally white, pale yellow, or pink. In both arid and semiarid climates, the presence of much unleached lime in the soils tends to whiten their colors.

The sources of Red-beds such as occur in our western states were igneous or sedimentary rocks containing iron in warm, moist climates, where decomposition reached an advanced stage. The iron in the residual soils was oxidized to red or bright brick-red hematite. Such soils, with their ferric iron, were transported away from the warm, moist climates and deposited for the most part as fine-grained clays and sands along stream courses and in lakes and enclosed seas, under arid conditions. The Permian Red-beds of western Texas are an example. Where such rock decay did not go so far, due either to more rapid removal by transportation, or to differences in climate, less of the iron was changed to hematite. Where the products of disintegration and partial decay were coarse, these were transported and deposited as sands and conglomerates, generally containing considerable mica or even feldspar. Their colors were gray, buff, yellow, brown, or red. The shales accompanying them were varie-

gated in colors of red, dark red, chocolate, or maroon, more of the iron in the finer sediments being in the form of hematite. The Triassic beds of western Texas are an example.

Continental deposits are forming now, in some parts of the world, on a large scale, and in the past have added considerably to our geologic column. Where streams carrying sediments leave the mountains and spread out over the floors of large valleys, alluvial fans, ranging in extent from a few square feet to thousands of square miles, are built. Where several of these fans come together, confluent fans of great dimensions may be formed. The Indo-Gangetic alluvial plain affords such an example.[1] It comprises an area of about 300,000 square miles. In its steeper portions, toward the mountains, its sediments grade into residual and atmospheric deposits. On its seaward side they grade into delta and marine deposits. River flood-plains are commonly widest in the regions of low relief. Deltas range in size from deposits at the mouths of small streams to areas covering thousands of square miles, such as the deltas of the Nile and the Mississippi. Subsidence of the land and encroachment by the sea will cause the delta deposits and then the continental sediments to be overlain by marine deposits. As examples of such ancient alluvial fan and delta deposits, Grabau[2] cites the following red formations: the Longwood shale of late Silurian age, the Catskill and Old Red sandstone of Devonian age, the Mauch Chunk of Mississippian age, and the Newark and Red-beds of Triassic age. He states that the red color in these deposits is regarded as indicating more or less arid climatic conditions during their formation.

The writer, following in the footsteps of Barrell, Russell, and Crosby, wishes to emphasize the important influence of climate on the genesis of the colors of sediments, especially on land or terrigenous deposits. Residual soils are commonly formed under one set of climatic conditions and deposited elsewhere under another; for example, deposits made near the head of a long river may be eroded and subsequently laid down in the delta of the river under different climatic conditions. In considering the effect of climate, however, it will not be feasible to point out all these changes, and the following discussion will be limited to the effect of a climate on the residual soil and alluvial and delta deposits formed in that particular climate.

[1] A. W. Grabau, *op. cit.*, 1913, p. 85.

[2] *Ibid.*

The effects of any climate on terrigenous deposits are necessarily modified by the nature of the parent rocks, their porosity, and the topography of the country.

The influence of the parent rocks is strongest on residual soils and local deposits. Igneous rocks with a large percentage of iron will disintegrate or decompose, giving more iron to the resulting products than will acidic igneous rocks. The same holds true on the outcrop of sedimentary strata. In north-central and northeastern Texas, the climate is practically uniform. However, in going from west to east over the outcropping formations, one finds that the blue-gray marls and shales of the Taylor and Navarro formations give brown or black residual soils and local stream deposits, while the middle and upper parts of the Wilcox and Mount Selman and Cook Mountain formations give buff or red residual soils and local stream deposits. In both cases the amount of vegetation present is about the same. In the former there is not much iron in the parent beds, but in the latter these strata are distinctly ferruginous. This is overcome to some extent by the accumulation of humus in the bottoms in the Wilcox-Claiborne areas, which reduces the iron and gives bluish-green to brown or black soils locally.

Due to their greater porosity, more air can circulate through the outcrops of sandstones and their residual soils than through the exposed beds of shales and silts. For this reason, their iron is the more readily oxidized and dehydrated. The outcrop of the Nacatoch sand in Hunt County, Texas, affords an excellent example. This sand in shallow wells is blue or white. On its outcrop it weathers to deep red residual soil, although the shales above it and below it form dark brown or black soils. Similarly, the sandy residual soils derived from the Lissie formation in Texas are red; the residual soils from the shales of the overlying and underlying formations are dark.

In regions of high relief, the water-table is likely to be low, resulting in the removal of carbonaceous material from the soil by oxidation. Also, oxidation of the iron will tend to take place, and if sufficient heat is present, dehydration will be advanced. In regions of low relief, where the water-table is relatively high, carbonaceous material will tend to accumulate, and iron, if present in the sediments, will be reduced. On a smaller scale, the same principle would apply to irregularities in the local topography, such as hills and valleys. Oxidation will be more effective above the water level on the hills, and humus will tend to accumulate in the stream valleys.

That climate does actually affect color of soils and their characteristics is shown by the following interesting experiment.[1]

A study was made of the physical, chemical, and bacteriological characteristics of the soils from plots of a tri-state soil exchange experiment. The plots are located at Maryland, Kansas, and California experiment stations. Soil from each state was exchanged with soil of the other states, and laid in position. After seven years the soils changed markedly in color. The Kansas and Maryland soils became a deeper red in California; the Kansas and California soils became bleached to a light gray or yellow-gray in Maryland.

Barrell divides climates into constantly rainy, intermittently rainy, subarid, and arid.

CONSTANTLY RAINY CLIMATES

Barrell[2] quotes Koppen[3] as defining constantly rainy climates as those where no month has less than fifteen rainy days, and adds that such climates are dominant south of south latitude 45°. Another large area exists in the North Atlantic, close to the shores of Ireland, Scotland, and Norway; and certain tropical areas, for instance, the northern half of the basin of the Amazon, also have very rainy climates, at least six days in every month being rainy. In cool, moist regions, vegetation may be nearly as heavy as in moist, tropical regions. Vegetation is profuse on our northwestern Pacific coast, and Russell[4] found a "luxuriant carpet of dense vegetation" covering the delta of the Yukon and the area south of it. As will be shown, the humus from such vegetation is largely destroyed in hot areas, and preserved in cool.

Red residual soils are being formed in our South Atlantic states at present, and throughout wide tropical and subtropical areas. Laterite, according to the estimates of Von Tille, covers 49 per cent of the surface of Africa, 16 per cent of Asia, and 43 per cent of South America.[5] Parts of these regions are densely wooded; but the heat of the sun is very great, bacteria flourish, and water vapor in the air hastens the work of oxida-

[1] C. B. Lipman and D. D. Wayrick, "A Detailed Study of the Effects of Climate on Important Properties of Soils," *Soil Science*, 1, 1916, pp. 1-48.

[2] J. Barrell, "Relation Between Climate and Terrestrial Deposits," *Jour. Geol.*, Vol. 16 (1908), p. 264.

[3] W. Koppen, *Bartholomew's Physical Atlas*, Vol. 3 (1889), Pl. 19.

[4] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.* Vol. 1, pp. 125-27.

[5] A. W. Grabau, *op. cit.*, p. 39.

tion, with the result that the carbonaceous material left upon the death of the vegetation is rapidly oxidized and removed from the soil. While the climate is moist, many days occur when it does not rain, and the heat is sufficient to dehydrate the iron, forming the red ferric oxide.

It seems paradoxical, but is a fact that the dehydration of the yellow or brown limonite ($2\ Fe_2O_3 \cdot 3\ H_2O$) forming the red hematite (Fe_2O_3) takes place in warm, moist climates much more rapidly than in hot, dry climates. The ferrous carbonate which is formed from the action of humic acids on the feldspars is almost instantly oxidized and hydrated to form limonite, This resulting product is seemingly unstable and is readily dehydrated by the heat to hematite. The process does not take place in hot, dry climates with the same facility. In Texas, along the Rio Grande, the writer has seen many outcrops of sandstone of Claiborne age in which the coloring agent was limonite. The outcrops of the resulting residual soil were yellowish-brown, or brown, in spite of the fact that the heat of the sun was intense for several months of the year. Graton[1] states that outcrops of limonite in New Mexico are not dehydrated to hematite by the heat of the sun. Neither does such dehydration of hydrous iron oxides take place in the laboratory except at very high temperatures. The writer suggests that in nature such dehydration of limonite to hematite takes place, due to the action of the sun's heat, on account of the quickness with which the limonite was formed and its resulting instability.

In our South Atlantic states, the residual red soil is generally but a few feet thick, though it may be washed into depressions and there reach thicknesses ranging from 30 to 50 feet.[2] Grabau states that the depth to which laterite extends may be very great; in Brazil it is more than 300 feet. In our northern Atlantic states, with rainfall very similar to that farther south, the residual soils resulting from the decay of much the same type of rocks are yellow or brown. Russell[3] noted this difference in color between the soils of the two sections, and states that the decay of the original rocks has proceeded to a greater depth in the warmer southern states. Crosby attributes this difference in color directly to the difference in temperature between the two sections. As further examples of red soils formed in hot, humid climates may be

[1]L. C. Graton, Harvard University. Personal communication to P. E. Raymond, and from him to the writer.

[2]W. O. Crosby, "On the Contrast of the Soils of High and Low Altitudes," *Amer. Geologist*, Vol. 8 (1891), pp. 72-82.

[3]I. C. Russell, "Subaerial Decay of Rocks," *U. S. Geol. Survey Bull. 52*, 1889.

mentioned the red clays of Bermuda, Jamaica, the Bahamas, and of southwestern Europe in the Istrian Peninsula and Dalmatia, Greece.[1]

Such red soils are residual land deposits, the iron and carbonaceous material being subjected to the full force of the oxygenation of the air. Deposits of carbonaceous material made under water where oxygenation is slower in subtropical and tropical regions, are brown or black, since deposits under water are better preserved. As examples, the cypress swamps of Florida contain thick deposits of peat.[2] In Bermuda, a thickness of at least 50 feet is assigned to the peat in one of the two great swamps of that island. Extensive peat swamps are also found in the Amazon region, and in the interior of Africa.

In traveling northward from the South Atlantic states, one finds that the residual soils, derived from much the same Appalachian rocks, become darker-colored. Yellow, brown, and black soils become prevalent. This is due to two causes: (1) the ferric iron is largely in the hydrous form of limonite or goethite, and (2) more carbonaceous material in the form of humus is preserved in the soils. The heat becomes less intense and has less influence in oxidizing and dehydrating the iron. The colder weather retards the action of bacteria in destroying the carbonaceous matter. That the accumulation of the latter may go on to a surprising extent is shown by the existence of extensive beds of peat upon the hillsides and uplands of eastern Canada, where a cool, moist climate prevails. These cover large areas in the vicinity of St. Lawrence and Ottawa rivers, as well as on Newfoundland and the smaller islands off the coast.[3] Thick accumulations of carbonaceous material in the form of mosses, earthy molds, and peat cover large parts of northern Germany, the hillsides in Great Britain and Scandinavia, and broad areas of northern Asia, and of Canada and the northern United States. Barrell[4] summarizes the case clearly:

> In cool climates. . . evaporation and oxidation are both diminished in intensity, with the result that carbon may accumulate upon slopes to an extent impossible in warmer climates, giving rise upon consolidation to carbonaceous sandstones, or even conglomerates.

These illustrations show the effects of climate on the preservation or destruction of carbonaceous material. Their value in this paper

[1] I. C. Russell, *op. cit.*, p. 46.

[2] A. W. Grabau, *op. cit.*, p. 509.

[3] *Ibid.*, pp. 501-8.

[4] J. Barrell, *op. cit.*, p. 258.

lies in the fact, before-mentioned, that carbonaceous material when preserved tends directly to color sediments gray to brown or black, and acts as a reducing agent to the red or yellow ferric iron, changing it to ferrous salts that give green or blue hues, or entirely removing it as ferrous carbonate. In general, the more humus contained, the blacker will be the soils, and the less iron they will contain. Exceptions will occur, as in our northern Atlantic states, where some of the sediments contain more iron than the amount of carbon present can reduce, and in such places they retain their yellow and red colors.

To sum up, superficial deposits, such as residual soils and allvium formed in cool, moist climates tend to be brown or black, as do those of deltas and flood plains of rivers in such areas. Rivers in cool, moist regions, especially where the topography is mature, as a rule, carry dark "loads" and deposit brown or black sediments in the ocean; the deposits made by St. Lawrence River afford an example. In hot, moist climates, red residual soils tend to be formed, and red sediments deposited by rivers on their flood plains and deltas. Such red sediments are also being deposited in the ocean opposite the mouth of some tropical rivers, such as the Amazon and the Yang-tze-Kiang.

INTERMITTENTLY RAINY CLIMATES

The characteristics of intermittently rainy climates are simply those of extremely moist climates in a modified degree. Barrell[1] defines intermittently rainy climates as those which characterize the areas of the world where irrigation is not necessary to the raising of crops, but where about two months of the year may be relatively free from rain. All the states lying east of Mississippi River and those contiguous west of the river, have such climates. The Atlantic states, mentioned before, really belong here.

Less vegetation grows in these areas and the resulting carbonaceous material is smaller in amount. In hot climates, its complete removal would favor the production of red soils.

In temperate climates with moderate rainfall, the amount of humus in the soils is generally sufficient to darken the sediments to grays, browns, and blacks, though in places it may not overcome the red and brown shades of the ferric oxide. It has been the writer's observation that in general the residual soils and stream deposits in the Mississippi Valley tend to be gray to brown or black, except in areas where the older rocks

[1] J. Barrell, *op. cit.*, p. 269.

crop out, which contain much iron oxide, such as the Lafayette of Louisiana and Texas, and the Wilcox and Mount Selman formations. In these areas, the amount of carbonaceous material in the soils may not be sufficient to reduce the large amount of hematite and limonite derived from the original formations, and the colors of the residual soils will tend to be yellow or red. This is especially true on hillsides and in high areas in which the ground-water level is low, with reference to the surface, and in sands and sandy soils which admit of better oxidation of the humus. However, in bottoms along stream courses in such areas in east Texas and Louisiana, the deposits are generally gray to brown or black, due to the greater amount of decaying vegetation accumulating in the low areas where the water level is relatively high. Blue and green colors are seen only locally and in low places.

SEMIARID CLIMATES

Semiarid climates have an annual rainfall of 10-20 inches per year and irrigation is necessary to raise crops. The western part of the Dakotas, Wyoming, the western parts of Nebraska, Kansas, Oklahoma, and Texas, have such climates. Vegetation is scarce, and the amount of humus formed is small. It is acted upon less readily by the oxygen of the dry air than is humus in wet climates, and fewer bacteria are present. However, the water level is low in dry regions, and oxygen can circulate through the soil and subsoil more readily than in moist climates. Hence, during the long periods of drouth, nearly all of the carbonaceous material is removed. Much of the iron in the soils and alluvium of semiarid regions is still in an unleached state and approaches that found in arid regions. The soils and alluvium tend to be light-colored, due to the causes next discussed under arid climates. Buff, grays, yellows, light browns, and some reds, predominate. Gypsum and salt are present in much less quantity than in truly arid regions, since the occasional heavy rains tend to dissolve them. Considerable quantities of calcium carbonate are deposited.

ARID CLIMATES

Arid climates in the temperate zone are described as those with less than 10 inches of rainfall annually. Areas with such climates, like those of true deserts, as a rule possess no drainage to the sea. However, due to the torrential nature of occasional rains, acting upon the disintegrated portions of the country rock, considerable stream deposits may be made. Aeolian deposits may be extensive.

The general absence of moisture in arid climates causes vegetation to be scarce, and the deposition of carbonaceous material slight. Such absence of moisture results in disintegration rather than decomposition of the rocks, and the colors of the resulting sediments are much influenced by the colors of the rocks from which they were derived. Light colors predominate, though in hot, arid regions more oxidation will take place than in cold. Russell[1] states:

> In the arid portion of the far West.... the color of the landscape, so far as it is influenced by the color of the sub-aerial deposits generally, is subdued and unobtrusive, being usually gray, or light yellowish-brown.

In doing reconnaissance oil work in Idaho, and in crossing Utah and Nevada, the writer was struck by the dull monotone of the deserts. Grays, buffs, and light browns were the prevailing hues.

Sediments derived from igneous rocks with pink or yellow feldspars, such as some of the granites, will be tinted pink or yellow when deposited in arid regions. The prevailing colors will be gray or gray-brown, however, since the feldspars are in general white to gray, and their undecomposed fragments, together with minute particles of iron, form an important part of the superficial deposits of arid regions. The iron is mostly in the form of undecomposed particles of black magnetite, ilmenite, and pyrite. In areas where these are locally oxidized, one will see yellow, brown, and red hues. That the feldspars may be important in the coloration of sedimentary rocks was proved by a microscopic examination made of 30 thin sections of Newark rocks gathered in quarries from Massachusetts to North Carolina. While all of the specimens examined were composed principally of angular quartz grains, many fragments of feldspar, hornblende, and mica were intermingled. Several of the rocks were gray, and derived their color from the inherent tints of the fragments composing them.[2]

Aeolian deposits are typical of arid regions. They are characteristically light in color, ranging from nearly white to pale yellow or pink.[3] In some places red aeolian deposits may be made in arid regions where the heat is sufficient to oxidize and dehydrate the iron. Barrell[4] states that red sands have been noticed in Africa and Asia, and adds that Phillips[5] has shown that the red sands of the Arabian desert owe their

[1] I. C. Russell, *op. cit.*, p. 27.

[2] *Ibid.*, p. 44.

[3] J. Barrell, *op. cit.*, p. 233.

[4] *Ibid.*, p. 287.

[5] J. A. Phillips, "The Red Sands of the Arabian Desert," *Quart. Jour. Geol. Soc. London*, Vol. 38, 1882.

color to a coating of ferric oxide deposited after the grains became round. He was unable to determine the source of the iron oxide which comprised about 1/500th of their total weight. The presence of the iron was probably caused by the evaporation of ascending waters brought up by capillary action. The writer believes that the red color of the residual soils of the Reynosa formation in southwest Texas is due to this cause.

Gypsum, lime, and salt accompany many lacustrine deposits in arid regions. In rocks of older geological age, for instance, the Permian of Oklahoma and northern Texas, the accompanying sediments are red. This is not characteristic of the areas where gypsum is forming at the present time. Barrell[1] remarks in this connection:

> This is in striking contrast to the usual present development of salt and gypsum in association with gray or yellow sediments. For example, the marginal bottom of the Dead Sea, when exposed by unusual dessication, shows a surface of bluish-gray clay or marl, full of crystals of common salt or gypsum, and light grays are characteristic also of the salty flats in the Great Basin of the United States. Furthermore, the Red Sea, surrounded by intensely arid lands, shows dominant light yellow as the color of the bottom muds, varying in certain soundings to tones of grayish- or brownish-yellow. Contrary to what might be expected from the name, the Red Sea contains no red sediments, and the origin of the name is in doubt.

Another factor that influences the color of the deposits of arid climates is the increase in the lime carbonate content of the sediments. This is especially high in delta deposits of arid regions, and its presence tends directly to lighten the color of the sediments. Upon aging, it may to a certain extent prevent the production of a red color by the formation of complex silicates of lime, iron, and alumina.[2] Ries[3] has shown that where clay containing little lime is burnt, red bricks are formed. If the clay contains three times as much lime as iron, a buff or cream color results. The writer has done some field work in the Redbeds of western Oklahoma and Texas, and observed that where the shales and sandstones were noticeably calcareous, their hues were light reds and pinks.

Examples of flood-plain and delta deposits in arid climates are those of the Volga, the Indus, the Nile, and the Colorado. Their sediments are noticeably high in lime carbonate. Fresh Nile muds contain as much as 22 per cent of lime, and old Nile muds 11 per cent, as against 1.38

[1] J. Barrell, *op. cit.*, p. 290.

[2] A. W. Grabau, *op. cit.*, p. 622.

[3] H. Ries, "Clays and Shales of Michigan," *Michigan Geol. Survey*, Vol. 8, Pt. 1, pp. 1-67.

per cent, the average for two analyses of alluvial soils in the Mississippi Valley.[1]

Briefly, in arid climates light colors, such as grays, light browns, yellows and buffs, predominate, though aeolian deposits in hot, arid climates may be red. The high content of lime, especially in delta and lake deposits of arid regions, tends to lighten their color.

RED-BEDS

As previously mentioned, most of the iron in red strata is in the form of the ferric oxide, hematite, or goethite. Where Red-beds are associated with gypsum and salt, their deposition under arid conditions is practically proven. This is true of many of the Red-beds of Texas, Oklahoma, and Kansas. Due to the writer's greater familiarity with this area, the following discussion will be largely confined to it.

The question of the source of the red coloring matter immediately arises. At the present time, the colors of strata being laid down under arid conditions in connection with gypsum and salt beds are commonly buff, gray, yellow, or brown.

Barrell[2] suggests that the Red-beds in our geologic column were deposited with lighter shades. Later, dehydration of the iron from the yellow and brown limonite, forming the red hematite, was caused by the great increase in pressure with a moderate rise in temperature, which took place with the burial of the material some thousands of feet. Barrell also favored the views of Crosby,[3] that such dehydration of the iron is spontaneous and increases with the age of the sediments, without the necessity of increased heat and pressure.

Tomlinson, in his able paper on Red-beds, refutes these older views and shows that the red coloring for the most part was mechanically transported from its place of origin as a stable compound in the form of films around the grains of the rock, or as fine particles of ferric oxide, which have not undergone much change since deposition. The evidence presented is very convincing, but lengthy, and will not be gone into here. The following quotations cover his conclusions, in part.

With reference to the source of red sediments, he states:[4]

> From the mineral composition of the clastic sediments, we may infer something of the condition of weathering and transportation which preceded

[1] J. Barrell, *op. cit.*, p. 278.

[2] *Ibid.*, p. 288.

[3] W. O. Crosby, "On the Contrast in the Color of the Soils of High and Low Altitudes," *Amer. Geol.*, Vol. 8 (1891), pp. 80-81.

[4] C. W. Tomlinson, *op. cit.*, pp. 248, 252.

their deposition. The high proportion of feldspar in many of the Red Bed shales and sandstones indicates a preponderance of mechanical disintegration over chemical decomposition. The abundance of undecomposed mica flakes in the Red Beds confirms this interpretation.....The areas from which the Red Beds derive their materials certainly included uplands; and in part at least they are known to have been possessed of fairly rugged relief; they were, therefore, in all probability the sites of more abundant rain than fell upon the plain or flats upon which the Red Beds were in large part deposited.

With reference to the manner in which the Red-beds were laid down, Tomlinson adds:

> The types of sediments most important in the Red Beds group are stream deposits, submarine fluviatile deposits, and playa deposits, all predominantly of red color, and all deriving the greater part of their ferric oxide from ferruginous red soils.[1]

In the previous chapters it was pointed out that red residual soil is being formed to-day on a large scale only in warm, moist climates where decomposition rather than disintegration takes place; the feldspars and micas are destroyed, liberating their iron, which is rapidly oxidized to limonite and then dehydrated by the sun's heat to hematite. Hence, the writer was at a loss to understand the statement of Tomlinson that the Red-beds of the western states contain a considerable portion of feldspar and mica, since disintegration of rocks with resultant mica and feldspar in the residual soil at the present day produces shades of gray, buff, yellow, or brown, most of the iron being in the form of magnetite, pyrite, or limonite. Recently, while doing oil work in western Texas, the writer examined many sections of Permian Red-beds of Clear Fork and Double Mountain age. Samples were gathered from outcrops in Jones, Nolan, Dickens, and Coke counties. Many of the specimens appeared to contain considerable mica, but upon examination with a strong hand lens in the field, and later under a more powerful glass in the office, it was seen that the many shining particles were flakes of gypsum or anhydrite. Only a few flakes of mica were seen.

Miss Hedwig Kniker, of San Angelo, Texas, has examined many specimens under the microscope from wells drilled into the Red-beds in Reagan, Upton, and Crane counties, Texas. She stated[2] that she had seen only a very small amount of mica in the samples examined, although many contained minute particles of gypsum. She had noticed no feldspar. J. W. Beede, the leading authority on the Permian

[1] *Op. cit.*, p. 253.

[2] Oral statement to the writer.

Red-beds of Texas, stated[1] that he had not observed much mica or feldspar in the Permian Red-beds of this state, though at a very few localities he had seen some,—notably at a point several miles west of Blackwell, in Coke County. In Oklahoma, on the flanks of the Wichita and Arbuckle Mountains, Dr. Beede stated that mica and feldspar were more plentiful in the Red-beds, but that there the colors of the strata were not uniformly red, many of the sandstones being buff or brown.

Most of the shales and sandstones of the Red-beds of western Texas are marine. As a rule, they are fine-grained in texture, as would result from long decay rather than disintegration of the parent rocks. In the sections of the Clear Fork and Double Mountain formations, which the writer examined, there is no definite relation between the coarseness of the grains and their color. While the fine-grained shales are commonly a deep red, the sands and sandy shales adjacent to them may have the same tint, or else a reddish-buff or pinkish hue. Most of the green shales and sandstones in the Clear Fork and Double Mountain formations were thin, ranging in thickness from a few inches to several feet. The shales ranged in color from gray-green to bright green, while most of the sandstones were gray-green, due to the large amount of quartz present. There was not much difference in texture between the green and the red sandstones or the green and the red shales.

The slight variations in color mentioned apply only to the more or less typically fine-grained strata of the Clear Fork and Double Mountain formations. A different condition is presented by the beds of the San Angelo formation, which is overlain by the Double Mountain and underlain by the Clear Fork, and until recently was regarded as the base of the Double Mountain formation. The San Angelo formation ranges from 100 to 250 feet in thickness and is composed of beds of red, green, and maroon shales with thick cross-bedded sandstones near the base and beds of conglomerate higher in the section. The colors of the sandstone are gray, greenish-gray, brown, yellow, and buff. The color of the matrix of the conglomerates is buff, shading to brown.[2] Mica is not plentiful in outcrops of the San Angelo formation, but the writer found more than in the Clear Fork and Double Mountain. The conglomerates and coarse sandstones of the San Angelo indicate a condition of disintegration and rapid transportation rather than slow decay at its source.

[1]Oral statement to the writer.

[2]J. W. Beede and D. D. Christner, "The San Angelo Formation," *Univ. of Texas Bull. 2607*, 1926, pp. 7-10, 29.

In Dickens and Nolan counties, Texas, the writer examined outcrops in the basal part of the Triassic system, which overlies the Double Mountain formation. The shales were dark red or wine-red in color, and contained much mica. It was easy to distinguish them from the underlying bright brick-red shales of the Permian, simply by their color. The contrast was pronounced. This difference in color between the Triassic shales and the Permian was noticed by Gould[1] in the Texas Panhandle. The sandstones of the Triassic were thick, coarse-grained, and exceedingly micaceous. Many of them contained pebbles, and beds of conglomerate were locally present. In color the sandstones were gray, yellowish-brown, or brown.

In Montague County, Texas, between the towns of Nocona and Bowie, the writer examined many outcrops of Pennsylvanian shale. These were wine-red, chocolate, or maroon. They contained much mica. Accompanying them were gray-green, medium coarse, micaceous sandstones, and a few beds of conglomerate containing fragments of feldspar.

It seems significant that the micaceous shales accompanying the light-colored, micaceous, coarse-grained sandstones and the conglomerates of the Triassic system of West Texas, the Pennsylvanian formation of north Texas, and to a less degree the San Angelo formation of West Texas, should be dark red, chocolate, maroon, or variegated, while the fine-grained shales and sandstones of typical Red-beds are bright brick-red. The mica in the shales and sandstones and the undecomposed feldspar in some of the conglomerates of the former group indicate a condition of disintegration, or, at best, only partial decomposition at their source. The absence of mica and feldspar and the uniformly fine texture of the latter group indicate a condition of thorough decomposition. In the former, the iron was only partially oxidized and dehydrated, producing the dark red, chocolate, or maroon shades. In the latter, it was fully oxidized and dehydrated to hematite, producing the bright brick-red shades.

The author agrees with Tomlinson that the red coloring matter in the Red-beds was mechanically transported and deposited as a stable compound which has not undergone much change since deposition. However, he differs from Tomlinson as to the interpretation given in the first paragraph quoted (p. 927) and would point out that mica and feldspar are absent or scarce in the typical bright red strata which make up the bulk of the Red-beds of western Texas. The scarcity of these

[1] C. N. Gould, "Geology and Water Resources of the Western Portion of the Panhandle of Texas," *U. S. Geol. Survey Water Supply Paper 191*, 1907, pp. 23-24.

minerals implies a condition of long-continued decay or chemical decomposition at the source of the red strata before transportation, and not a condition of mechanical disintegration, as suggested by Tomlinson. The former is consistent with the present-day conditions under which red residual soils and laterite are being formed.

The writer's picture of the origin of Red-beds in these areas is as follows. The sources of the materials were igneous or sedimentary rocks which contained iron, in regions of fairly high relief, with warm, moist climates. The latter must be postulated, as at the present time red soils are being formed on a large scale only in such climates. The decay of the parent rocks produced red residual soils which were transported by streams with their red coloring matter unchanged, and deposited along their courses in regions of lower relief with arid climates, and in inclosed lakes and seas which had so great a salinity that little animal or vegetable life was possible. This condition must have existed, for the red ferric oxides of these sediments would have been reduced by carbonaceous material had it been present. The scarcity of animal or plant remains in the Red-beds confirms this hypothesis, and accompanying beds of salt and gypsum are evidence of the salinity of the waters in which the red strata were laid down.

Where the decay of the parent rocks in warm, moist climates was long continued before transportation removed the residual soils, the iron was completely oxidized and dehydrated to hematite. Due to this prolonged decomposition, the residual soils were finer-grained, and most of the mica and feldspar removed. Such soils were transported by streams and laid down along their courses and in lakes and seas in arid regions, to form typical bright red strata such as are found in the Clear Fork and Double Mountain formations of western Texas.

At times when transportation removed the residual soils from their source before the iron which they contained had been completely oxidized and dehydrated, the sediments which the streams carried away were coarse sands and conglomerates mixed with the finer particles of clay containing either mica or feldspar, or both. When these were deposited, the colors of the sandstones and conglomerates were buff, yellow, or brown, because much of the iron coloring matter was still in the form of limonite or goethite. The shales were variously colored; wine-red, maroon, gray, and green were intercalated with typically bright red shales. The iron was only partially oxidized and dehydrated to hematite. The Triassic beds of western Texas are an example.

III

COLOR OF MARINE SEDIMENTS. LITHIFICATION

ABSTRACT

Wave action carries iron and carbonaceous material from the shallow areas of the sea and deposits them in deeper waters. For this reason, the sands of the littoral zone are, in general, white, gray, yellow, or brown; the former colors being due to large amounts of quartz present, the latter to different amounts of iron. In the deeper parts of the continental shelf and epeiric seas, the sediments become finer, and, as a rule, darker, due to increased amounts of organic material and iron.

Bluish-gray mud is being laid down at present on a large scale in the deeper and quieter waters of the continental shelf and on the slope. Glauconitic greensand is being laid down locally on the continental shelf near the mud line. It grades seaward into green mud, which is similar to the blue mud, but colored by fine particles of glauconite.

Red muds are now being deposited opposite the mouths of some tropical rivers, but beneath their surface these red muds change to gray. The red clay of the abysmal depths owes its color to the slow oxidation of volcanic material.

Black marine shales are being deposited in inclosed portions of the sea where the wave action is slight. They owe their color to the accumulation of organic matter.

The common cementing materials of sandstones and conglomerates are lime, silica, and iron oxide. Lime tends to whiten rocks, and silica to give them a neutral gray shade. Limonite as a cement colors rocks yellow or brown, and if dehydrated to hematite, purple or red.

Induration of sediments tends to darken them by bringing their particles closer together, but there has probably not been much change in the color of most sediments since they were laid down. The present-day green, blue-gray, and black marine muds are probably the counterparts of the source rocks of the green, blue-gray, and black shales in our geologic section. Our Red-beds were laid down as such.

In a discussion of the color of marine sediments, a brief resumé of the conditions under which they have been and are now being laid down, will be helpful. Schuchert[1] states that the continental shelf extends seaward to a depth of about 100 fathoms (600 feet), where the effects of wave action are no longer felt. The deposits on the continental shelf and epeiric (lying over continents) seas, such as Hudson Bay and the Baltic Sea, are classed together. The importance of sediments laid down in ancient epeiric seas cannot be overestimated. Most of the marine strata which occur in the geologic column from the Cambrian to the present were laid down in such seas. These are believed to have been shallow—generally less than 600 feet in depth—though it is probable that in places they were deeper. At present the continental shelf and epeiric seas cover approximately 10,000,000 square miles. Beyond the edge of the continental shelf there is a fairly rapid descent to the oceanic basins, which Schuchert calls the "continental slope." The agitated waters above the continental shelf are capable of holding mud in suspension,

[1] L. V. Pirsson and Charles Schuchert, *Textbook of Geology*, Pt. 2, 1915, pp. 470-79.

and it is at the edge of the shelf and on the slope that mud and silts are deposited.

Near the shore on the continental shelf and in epeiric seas is the strand area which lies between high and low tide. Here the deposits differ in composition and are coarse in grain. The littoral region covers the zone from the lower limit of the strand to a depth of 150 feet. At this depth the undertow ceases, and the waves lose their power to assort the sediments. The deposits range from conglomerates to clean coarse sand, dirty consolidated sand, and the coarser muds. In this zone are laid down the off-shore portions of deltas.

Beyond the littoral area is the pelitic or mud zone, where the waters range from 150 to 600 feet in depth. Here the power of wave action is very small, but the sediments are stirred by tidal and oceanic currents. The deposits are well-assorted, fine sands and sandy clays, and some muds.

At a depth of about 100 fathoms the continental slope commences. On protected coasts, due to lessened wave action, it may begin at 300 to 400 feet. In general, this slope is not steep, compared with surface hills, but is long and smooth with a grade ranging from one foot in ten, to one foot in thirty. On it are deposited the fine-grained muds derived from the land, coral mud, and volcanic ash of coarser grains. This region covers about 18,000,000 square miles of the ocean bottom.

Beyond the continental slope are the oceanic abysses in which the deposits consist of red clay, containing much volcanic débris, and organic (pelagic) oozes of different types. These deep-sea deposits have probably entered little into the geologic column, and will be discussed no further.

STRAND AND LITTORAL DEPOSITS

The sands and sandy shales of the strand, littoral, and shallower parts of the pelitic zone are apt to be light-colored, due to the action of the waves, which carry pebbles and sand back and forth. This constant wave movement causes friction and impact which tend to break up any films of ferric oxide around the grains, and the iron in its more finely divided state is carried into deeper waters. Some organic material is brought in by streams, but probably most is derived from the remains of animal and plant life which abounds in the shallower sunlit waters of the littoral zone. However, little of this dead organic material is itself deposited in the sands or conglomerates of the littoral zone, except in quiet inclosed areas, where it may be incorporated in black shales. Constant wave action carries it to the quieter waters of the deeper part of the con-

tinental shelf, or to the slope, where it settles with the muds. Again oxidation helps to remove dead organic matter. Oxygen occurs in all the shallow and surface waters of the ocean in amounts ranging from 13.73 cubic centimeters per liter, to 28.58 cubic centimeters per liter.[1] Due to the oxygen, bacteria are present, and are an important factor in the decay and removal of organic material.

In general, the sands along the littoral zone are white, gray, or shades of yellow and brown, the former colors being due to the large amount of quartz present, the latter to different amounts of iron. Locally there are darker deposits due to the nature of the materials from which the sands and conglomerates are derived. Grabau[2] cites deposits of green sand in shallow waters, due to the erosion of Cretaceous glauconitic sands along the Atlantic coast. Where granite or other igneous rocks form the shore line, feldspathic arkoses may be incorporated into the marine strata.[3] This is being done to-day in the Gulf of California. In these cases decomposition does not take place, and the color of the sands may be pink, yellow, or even black, due to the undecomposed minerals present.

Delta deposits are laid down in the littoral and pelitic zones, but unless the sea coast is sinking they are base-levelled by wave action, and only the more seaward portions remain.

DEPOSITS OF THE PELITIC ZONE AND CONTINENTAL SLOPE

The waters of the continental shelf and epeiric seas become deeper in going from the littoral zone to the pelitic. The sediments become finer, and, as a rule, darker. This is due to the great amount of sarbonaceous material preserved because of the lessened wave action, the smaller amount of oxygen, and the resulting decrease in the number of bacteria. Schuchert[4] states that areas of mud deposition are as a rule devoid of attached seaweeds, and that animal life is scant. Their organic material is derived from the remains of the abundant plant and animal life of the littoral zone brought out by currents, and from the remains of pelagic forms, which on their death fall from the surface waters to the bottom. In the deeper parts of the continental shelf and on the slope, blue, green, black, and red muds are at present being laid down. Similar muds have in past times been incorporated into the geologic column, accounting for the fact that most shales are darker than sandstones.

[1] F. W. Clarke, *op. cit.*, pp. 143-45.

[2] A. W. Grabau, *op. cit.*, p. 673.

[3] *Ibid.*, p. 652.

[4] Charles Schuchert, *op. cit.*, p. 494.

Schuchert[1] says:

> In any classification it is difficult to draw a sharp line, and though the great mass of blue mud is laid down beyond the continental edge and mostly on the continental slope, still it is also found in the quieter water of less than 600 feet depth. This blue mud owes its blue color to the fact that the iron of the mud is united with organic matter.

As already mentioned, this mud is really blue-gray or gray. Grabau[2] distinguishes three types of land-derived or terrigenous muds being deposited on the modern sea bottom, the blue, the red, and the green muds. The blue (or gray) mud is being deposited throughout an area of 14,500,000 square miles, and covers the epicontinental slope to a depth of 1,400 fathoms. It is pertinent to notice that Grabau believes that most of the marine shales in our geologic column were derived from this type of mud.

Green mud is being laid down on the ocean floor at depths of 180-2,300 meters.[3] These green muds grade into glauconitic sands at shallower depths. The area covered by green sands and green muds in the ocean is 850,000 square miles. Glauconite is a green ferric potassium silicate represented by the formula $Fe''' KSi_2O_6 \cdot aq$.[4] With reference to its origin, Clarke[5] states:

> In oceanic sediments, chiefly near the mud line surrounding the continental shores, the important mineral glauconite is found in the actual process of formation. . . . As an oceanic deposit, glauconite is developed principally in the interior of shells, and organic matter is believed to play a part in its formation. According to Murray and Renaud, the shell is first filled with fine silt or mud upon which the organic material of the dead animal can act. Through intervention of the sulphates in the sea water, the iron of the mud is converted into sulphide which oxidizes later to ferric oxide. At the same time, alumina is removed from the sediments by solution, and colloidal silica is liberated. The latter reacts upon the ferric hydroxide in the presence of potassium salts extracted from adjacent minerals, and so glauconite is formed.

Grabau[6] believes the glauconite is formed chiefly in the interior of foraminiferal shells.

Red muds are now being deposited opposite the mouths of tropical rivers, such as the Amazon and the Yang-tze-Kiang, throughout an area

[1] *Op. cit.*, p. 478.

[2] A. W. Grabau, *op. cit.*, p. 68.

[3] *Ibid.*, pp. 668-70.

[4] F. W. Clarke, *op. cit.*, p. 521.

[5] *Ibid.*, pp. 519-20.

[6] A. W. Grabau, *op. cit.*, p. 670.

of approximately 100,000 square miles. These rivers carry a red load of laterite, or residual soil. The red ferric oxide, hematite, is not reduced during transportation and deposition. However, these delta deposits contain many marine shells and some decaying vegetable matter. The organic matter derived from them in time reduces the ferric oxide. Beneath the surface, the red muds opposite the mouth of the Amazon are changed to gray.[1]

Except in inclosed seas in arid regions, where the waters are so concentrated that animal and vegetable life cannot exist, it is not likely that red terrigenous muds will retain their color after reaching the ocean. The red clay of the oceanic depth has a different origin. It is largely the product of the decay of volcanic material.

BLACK SHALES

Black muds are deposited in estuaries, lagoons, and inclosed parts of the sea, where the water is relatively quiet and wave action slight; also in depressions on the continental shelf where there is little current, and on the edge of the continental slope.

In such stagnant areas there is little sea life, due to the scarcity of oxygen. Currents, however, bring in remains of plant and animal life from the littoral zone, and the remains of countless pelagic forms such as algae, *Foraminifera*, diatoms, and *Radiolaria* fall from the sunlit surface waters to the muds at the bottom.[2] These become "stale." Sulphur-making bacteria feed upon the organic remains, liberating H_2S, and a foul organic slime results.

The excessive accumulation of carbonaceous material colors the muds brown and black, or black. The sulphuretted hydrogen acts on the iron silicates of the sea floor to form pyrite or marcasite.[3] It is not uncommon to find these minerals in black shales, and they are present in many blue-gray shales.

Black shales may be laid down in the deeper parts of fresh-water lakes and swamps, but the marine organic deposits generally have a higher proportion of fat and protein.[4] Marine deposits, for the most part, are much richer in the hydrocarbons, which are the source of our oil; fresh-water organic shales are richer in cellulose and peat-making material, or the carbohydrates.

[1]Personal communication from Eliot Blackwelder to P. E. Raymond, and from him to the writer.

[2]Charles Schuchert, *op. cit.*, pp. 493-94.

[3]F. W. Clarke, *op. cit.*, p. 150.

[4]A. W. Grabau, *op. cit.*, pp. 478-501.

LITHIFICATION

As sands and clays of both continental and marine clastics are buried under succeeding sediments, they tend to consolidate; the sands to sandstone (or, in rare instances, to quartzite); the clays to shales; and the shales to slates. This metamorphism is, as a rule, accompanied by a decrease in porosity and water content and a reduction in volume.

In sandstones, pressure alone may be effective in causing induration; but cementation is a much more important factor. Percolating underground waters deposit cementing materials which partially or completely fill the pores between the sand grains. Silica, calcium carbonate, and iron oxides are the most common minerals to form such cements. Addition of siliceous cements, if pure, tends to give the rock a more neutral shade of gray or brown. Calcium carbonate tends to lighten the color of the rock, producing in some sands or conglomerates a pure white or gray matrix. Iron hydroxide in the form of limonite, which is the most common of the iron cements, gives yellow or brown tints to the matrix. The iron is probably distributed in the form of the soluble ferrous carbonate, which in the presence of oxygen readily oxidizes to limonite, when the excess CO_2 is removed. Dehydration of the limonite to hematite gives the matrix a red shade. Cementation in sedimentary rocks is confined to the comparatively shallow zone of active water circulation. When shales and sandstones are buried beneath the groundwater level there is little circulation of water except along fault planes or in strata between such fault planes and their outcrops. The active movement of meteoric water is confined mostly to the zone between the point of intake of surface water and the lowest point of outlet. This is measured by the relief or topography of the surface of the country.

Clays consolidate into shales through a sort of welding. Clarke[1] states:

> The colloidal matter contained in most muds and clays is capable of binding under pressure alone; and to unions of this kind a shale owes its coherence. Cementation is not excluded, but it has become a subordinate factor. Under the influence of pressure, the water of a mud is largely expelled, so that the resulting shale is much less hydrous.

The particles of shale are brought so close together that they cohere by molecular attraction. In changing from clay to shales, the colloidal aluminous silicates, silica, and ferric hydroxide pass over into crystalline substances, the clay losing much of its plasticity. In speaking of analyses

[1] F. W. Clarke, *op. cit.*, p. 552.

of shale made in the laboratory of the U. S. Geological Survey, Clarke states:

> The most noticeable feature in these analyses as compared with analyses of similar clays is the change in the iron oxides. In the shales the proportion of ferrous oxide relatively to ferric has increased, probably because of the reducing action of organic matter in the sediments as they were first laid down. Ferric oxide has been evidently reduced, and organic substances furnish the most obvious reagents for producing such an alteration.

These reactions would naturally tend to alter yellow or red clays to green, bluish-gray, or gray shales. The writer questions whether this reduction has operated to any great extent in changing the color of sediments during lithification, except in its early stages. Clays, on becoming indurated to shale, gradually become impervious to the circulation of water and air.

As previously mentioned in the section on Red-beds, Barrell believes that dehydration of iron by great increase in heat and pressure causes the yellow and brown limonitic coloring matter to change to red hematite, while Crosby believes that this process is spontaneous. The writer agrees with Tomlinson and questions the extent of such dehydration due to increase in heat and pressure caused by the overlying sediments. He believes the Red-beds were of that color when laid down. Yellow and brown sandstones are common in the Pennsylvanian and older rocks that have been buried under great thickness of overlying sediments. The limonite has not been dehydrated to hematite.

Compression would have a slight general tendency to darken or deepen the original color of sedimentary rocks, by reducing their volume and bringing the particles of coloring matter closer together.

The writer has not been able to find much in the literature with reference to change of color due to induration. Except for the alterations mentioned, due to cementation and the reduction of the iron oxides by organic material during the early stages of lithification, the writer questions whether there has been much change in the color of sedimentary rocks since they were first laid down. In all probability most of the white, gray, green, blue-gray, brown, black, and red strata in our geologic column were deposited with these colors.

RESEARCH AND THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS[1]

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ABSTRACT

Members of the American Association of Petroleum Geologists are engaged in serving the petroleum industry; fundamentally, however, they are geologists with a broader vision than the mere economic aspect of their work. They should lend both interest and active support to geologic work that seems to fall in the realm of pure science. Matters of purely academic interest to-day may be of utmost economic importance to-morrow. Geologists of the Association have exceptional opportunities to serve the science which brings them their livelihood,—opportunities of observation in remote fields and investigation of unsolved problems. More specifically, as petroleum geologists, they must be interested in the realm of engineering, recognizing the importance of physics, chemistry, and mathematics. There are three organizations through which they can work to advance organized studies of the geologic and engineering problems of the petroleum industry, namely, the American Association of Petroleum Geologists, the National Research Council, and the American Petroleum Institute.

Should the American Association of Petroleum Geologists engage in research activities? If so, should it initiate work or should it merely support work that has been started by some other organization? What should be its official attitude concerning research activities with a bearing on petroleum geology or petroleum engineering that may be in progress under other auspices? These and other questions that have been seriously raised by members of the Association show that there is some diversity of opinion concerning the course that the Association should take with respect to research. Other statements, questions, and criticisms that have reached the writer show that there is some uncertainty as to the scope and functions of the National Research Council and the American Petroleum Institute, the two organizations that are most actively fostering research in problems of petroleum geology. They also seem to manifest a growing desire to be acquainted with current scientific studies that may help us solve some of the many geological, chemical, and physical problems that confront us and that force us all too often to work

[1]Read before the Association at the San Francisco meeting, March 21, 1928. Manuscript received by the editor, May 18, 1928.

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in the realm of assumption and theory rather than in that of sound and demonstrated fact.

Geologists are traditionally interested in any study that promises to add basic facts to their science or to illuminate the theories with which they deal. The fact that through applied geology we try to help the petroleum industry does not make us any the less geologists, and probably there are few among the members of this Association who do not have keen interest in some pet problem that seems to have no economic application. Many of the members, including the writer, feel that we should lend both interest and active support to geologic work that seems to fall in the realm of pure science. For the more practical-minded we may urge that it is never possible to know what branch of science will leap from the high ground of pure academic interest into the thick of the economic battle. Not long ago many economic geologists could not be bothered with paleontology. To-day we can point to oil fields that have been opened because, through paleontology, critical structural and stratigraphic relations were recognized, and to other districts that were most ineffectively prospected because men who ranked high in their profession would not waste their time in collecting shells. Professors have solemnly told classes that physiography was the purest and most useless branch of geology, while practical oil operators were finding fields by using "creekology." Seismology was a subject that was forced on the student in college and then promptly forgotten. Willis T. Lee's early efforts to arouse interest in the geologic possibilities of airplane mapping for the most part fell on deaf ears. With instances such as these fresh in our memories, is it safe to withhold interest and support from any geologic study that is being conducted under promising auspices, even though we may be interested only in applied science?

The geologists of this Association have exceptional opportunities to serve that science which brings them their livelihood. Their work takes them to remote places. It calls for observation of meticulous exactness. They are trained to see and record many things which geologists of an earlier generation were wont to pass by as without significance. Few of the founders of geology had such opportunity to visit areas of diverse geologic interest as have many members of this organization. If some among our number do not gain places among the great of their science, surely the failure cannot be ascribed to lack of opportunity.

Since we are not only geologists, but, specifically, petroleum geologists, we must be interested in certain of the facts and theories that fall in the realm of engineering, for no one can say where the field of the pe-

troleum geologist ends and the field of the production man and petroleum engineer begins. We are charged not only with the finding of the oil, but we must also judge as to the importance of our discovery and help effect the most economical recovery of the oil. The extraction of oil from the earth depends, in the last analysis, upon geologic conditions such as structure, character of reservoir bed, and relation to oil-field waters. This overlap on the field of engineering means that we must recognize the importance of much work in physics, in chemistry, and in mathematics, for the art of engineering is but the application of the principles that make up these natural sciences.

There are three organizations through which the petroleum geologist can work to advance organized studies of the geologic and engineering problems of the petroleum industry. He may lend his help to work already organized and under way. He may also bring to these organizations problems that, due to lack of time, of capacity, or of equipment, have outgrown his own ability to handle them. This does not mean that all work of a research nature should be done through these organizations. Far from it! Some of the most effective research has been the product of the individual rather than of the group. However, the field geologist often feels the lack of libraries, of laboratories, and of men who have specialized in such fields as chemistry, physics, bacteriology, or mathematics, and promising studies must lie uncompleted or be given to the public in an unsatisfactory and unfinished shape unless the needs for some highly specialized type of help can be met. A good example is the study, now under way, of bottom samples from marine and brackish waters. The first steps called for careful observation, collection, distillation, determination of acidity, and several other operations that could be satisfactorily performed by the research man. Then it was decided that it was important to learn the rôle played by bacteria in converting the fresh organic matter present in the upper parts of the sediments into hydrocarbons, if indeed such conversion takes place, and a bacteriologist who has spent much of his life in studying the action of bacteria on organic matter in soils and swamps was immediately added to the advisory group that is guiding that particular project.

The first of the three organizations referred to is the American Association of Petroleum Geologists. This Association has a Committee on Research, charged with fostering studies relating to petroleum geology. It was the first such organization in the field and the part it played in arousing interest and securing support from other organizations would have justified its existence had it never done anything else. However,

it still exists and it is hoped that it will take an increasingly important part in the advance of geologic knowledge. This committee has a small fund at its disposal, raised by contributions from individual members of the Association, but it is not the purpose, nor does it seem to the writer that it is the function, of this committee to engage in activities that necessarily call for large expenditures. There are many problems of great importance that depend more on the collection and organization of existing information, under the direction of some energetic and gifted man, than they do on funds. A case in point is the study of the relation of geologic structure to oil fields. Most of the members of this Association are familiar with the fact that this project, under the direction of Sidney Powers, was responsible for the remarkable collection of papers on geologic structure that were assembled and many of which were delivered at the annual meeting of 1927. This project is far from completed, for ultimately this material must be studied and coördinated, and it is hoped and believed that a treatise with some such title as "The Relation of Oil Fields to Geologic Structure," that will be a help and joy to every man in this organization, will be prepared.[1] However, the initial steps alone made it evident that much can be done by this method.

This Committee on Research of the Association should be the starting point for many research projects. It should be the agency to which the geologist with a problem but without the facilities for working it out can turn for help. It should recognize problems that can be handled through a coöperative attack by members of the Association and should organize such attacks and maintain contact with them until they are pushed to completion. It should establish contact with universities, government departments, scientific foundations and other agencies that are conducting scientific work of a type that may have a bearing on our own science, so that such other organizations may be aware of the existence of the American Association of Petroleum Geologists, of its interest in and desire to advance research in geology, of the ability of the Association to reach into remote parts of the earth for scientific information, and of the fund of knowledge and of scientific material that is accessible to our members. It should be the source of information for the man who wants to establish contact with men who are authorities on certain districts or who are known to have studied certain subjects relating to petroleum geology. In short, it should be constituted and should function to help our own members develop their ideas, to help and induce

[1] These papers are being published in the Association's new book, *Structure of Typical American Oil Fields.*

others to work on problems whose solution promises to aid our science, and, above all, to serve, actively rather than passively, the need of our organization for a broader, firmer foundation for geology as a whole and for petroleum geology in particular.

The second of the three organizations through which the petroleum geologist can work to attack the unsolved basic problems of petroleum geology is the National Research Council. This is "a coöperative organization of the scientific men of America," organized under the congressional charter of the National Academy of Sciences. Its function is "to stimulate research in the mathematical, physical and biological sciences," "to formulate comprehensive projects of research," "to promote cöoperation in research," "to gather and collate scientific and technical information," and in other ways to endeavor to advance scientific knowledge. The Division of Geology and Geography of the National Research Council includes representatives of the major geological and geographical organizations of the United States, and the American Association of Petroleum Geologists is represented by two members. Our representatives at this time are Sidney Powers and Alex W. McCoy. One of the committees of the Division of Geology and Geography is the Committee on Studies in Petroleum Geology, and the members of that committee are also members of the American Association of Petroleum Geologists. Some of the representatives of the Geological Society of America are also members of the American Association of Petroleum Geologists. The petroleum geologists are assured of a hearing and of coöperation whenever they have anything to present that truly deserves interest and help. Through the National Research Council they can perhaps secure a more intimate and effective contact with universities, foundations, government bureaus, and other organizations that conduct research than they could secure in any other way.

The National Research Council has no great endowment, and it is therefore not to be looked on as a source of funds with which to finance work. It does, however, when it seems justifiable, authorize its divisions to solicit funds for a definite purpose, and the endorsement of the National Research Council and the helpful coöperation of its members has been effective in obtaining the financial assistance needed in many instances. Furthermore, the machinery of the National Research Council for organizing research has been utilized by many organizations in the United States. Funds have been made available to be expended on specific studies and the Council has accepted the responsibility of seeing that the work is organized and effectively conducted. The only such

fund that has been devoted solely to work on petroleum geology was the James H. Gardner fund for the study of the Cromwell field, the results of which are now beginning to appear in the paper by Oliver R. Grawe on "Stratigraphy and Structure of the Cromwell Oil Field in Oklahoma," delivered at the San Francisco meeting of the American Association of Petroleum Geologists, and the paper by Ransome E. Somers on "Petrographic Criteria of Structure in the Cromwell Oil Field, Oklahoma," delivered at the Cleveland meeting of the Society of Economic Geologists in December, 1927.

The Committee on Studies in Petroleum Geology of the National Research Council and the Committee on Research of the American Association of Petroleum Geologists are really complementary groups. They have coöperated closely ever since their inception, and there is no clear-cut line of demarcation between their functions. Members of the Association have quite the same right to ask the one as the other for help in working out their ideas. However, it is to be expected and it is desirable that the American Association of Petroleum Geologists' own committee should at all times be in closer contact with the wants and needs of the members than is the more remote organization, and that it should be the organization through which the Executive Committee, groups of members, and individual members should work, at least in the initiation of research work, and in the conduct of projects that can be satisfactorily handled without calling on outside agencies for help.

The third organization to which we may look for help in the attack on problems in petroleum geology is the American Petroleum Institute. About two years ago John D. Rockefeller made available $250,000, payable in annual installments of $50,000, for scientific research in the geology, physics, and chemistry of petroleum. A little later the Universal Oil Products Company of Chicago donated an equal amount. These funds were placed at the disposal of the American Petroleum Institute. The Institute sought and obtained the advice and coöperation of the National Research Council in the selection, organization, and prosecution of projects. The Council, in turn, called on scientists who had specialized in the different subjects to select the problems that should be studied. The geologists were much better prepared than were the physicists and chemists, for the geologists had anticipated the ultimate availability of funds, and had, at joint meetings of the Committee on Research of the American Association of Petroleum Geologists and the Committee on Studies in Petroleum Geology of the National Research Council, discussed and selected problems for study. These problems were formu-

lated and in shape to be submitted for financing. Finally, projects were approved by the American Petroleum Institute, but not until a brief outline of the proposed work had been published so that the members of the Institute could make suggestions or criticisms should they see fit. Under this plan, work is now in progress on geological problems, on engineering problems that have to do primarily with physics, on physical problems that pertain to the fundamentals of oil migration and retention by sands, and on physical and chemical problems that promise to throw light on the actual make-up of petroleum data that have long been greatly needed by the petroleum geologist.

There seems to be still some misunderstanding about this fund that is administered by the American Petroleum Institute with the advice of the National Research Council. Many criticisms, some helpful, others merely destructive, have been made. Most of them may be explained by lack of familiarity with the restrictions that were placed on the funds when they were donated by Mr. Rockefeller and by the Universal Oil Products Company. These funds are to be spent for study of fundamentals and are not to be applied to studies that have a direct and primary economic bearing. This automatically rules out many problems that the oil geologist might like to see attacked. However, if science will give us the requisite tools, we should be able to build with them.

Perhaps the prevailing misconceptions can be most easily illustrated by actually mentioning some of the criticisms. A geologist writes, "Practically all the executives I know best are definitely opposed to a program of general geological research—that is, research of the sort that universities and governmental bureaus can conduct." Plainly this particular critic was not familiar with the provision that the money must be spent on non-economic problems. It also suggests that his acquaintance with executives is not extensive, for the writer has had the pleasure of talking with several who are as keenly alive to the need of fundamental science in the petroleum industry as are the executives of the automobile industry, of the electrical industry, and of the steel industry to the need for fundamental data upon which to base their applied science.

Again, a geologist writes, "There are fields of research where financial returns can be hoped for. If this is so, do you think it right to use this first money for probing the problem of 'Generation of Oil in Rocks by Shearing Pressures?'" I am sure this geologist knows a good deal about the occurrence of oil in faulted structures. He may have taken part in discussions as to whether or not the faulting itself is in any way

responsible for the generation of the oil that was found in the associated pools. There has been speculation as to whether the belts of en echelon faults in Oklahoma, and other areas where intricate faulting occurs, as, for example, the Lost Soldier field of Wyoming and the fault-line fields of Texas, owe at least a part of their oil to pressure and temperature induced by the forces that produced the faults or to conditions that would be present only when source rocks slipped and slid over each other. Geologists have inquired as to the depth of burial that would be needed to give enough pressure to raise the temperature to a point where organic matter would be broken down to liquid hydrocarbon, and what combination of static load and of active pressure might be effective. It seems to the writer that this particular project should give information that will be used by petroleum geologists all over the world under a multitude of different conditions, and that we are to be congratulated that it is being handled by men whose skill in developing and conducting an experimental attack on problems of geology is well recognized, and in an environment where facilities for conducting the work are assured.

A problem that was suggested to take the place of some of the work now in progress is "How to handle this miserable sulphur oil of West Texas cheaply—in pipes, in tanks and in the refinery,—especially in the refinery. I think most of the chemical funds should be spent in a concentrated effort to develop if possible a cheap refinery process to handle this oil." It is obvious that the man who made this suggestion was not familiar with the prohibition against projects with an immediate and restricted economic purpose, or that will be of primary benefit to a restricted group. It is also evident that he is interested in West Texas oil. Finally, it is evident that he had not carefully considered the chemical projects that he would replace, for had he done so he would have noticed two that are concerned with the isolation and identification of the sulphur compounds in petroleum. Under the restrictions of this research plan it is not permissible to work with the sole idea of handling West Texas oil. On the other hand, the chemists of the petroleum industry almost with one voice cry, "Tell us what the sulphur compounds are and what their properties are and we will handle them." If these basic studies are successful they can be used not only by the man who has the "miserable sulphur oil of West Texas," but also the man who has the oil even higher in sulphur of Huntington Beach, California, the sulphur-bearing oil of the Embar and Sundance formations of Wyoming, of the cap-rock fields of the Gulf Coast, of the McClosky sand of Illinois, of the Trenton "pay" of Ohio and Indiana, of the limestone fields of Texas,

—in fact, of all the fields where the sulphur in the oil is a source of loss to the producer, the refiner, and the marketer.

Another problem that has been suggested is "Continued intensive study of the problem of corrosion." This is recognized as a real problem. In fact, it is commonly looked on as one of the major problems not only of the petroleum industry, but of every industry that works with much equipment made of iron and steel. Studies of corrosion have been conducted by both private and governmental agencies and in spite of the many years through which this has been a subject of research it is generally felt that only a start has been made toward understanding it. However, the very importance and obviousness of this problem insure its being attacked by many organizations in the petroleum industry as well as by other industries. It is felt that the present need is to become familiar with what the different agencies are doing, confident that good progress is being made and recognizing that the addition of a few research workers to the field would make comparatively little difference in the gross results. The funds are so limited that they cannot be devoted to work that may be merely a duplication of other work in progress under either public or private auspices.

A fourth suggestion was for "a thorough exposition of all geophysical instruments and methods." Such a study might qualify because of its undoubted general scientific importance, in spite of its evident economic aim, were it not that this proposed study transgresses into the field that must be reserved to the individual company. All industries that have engaged in coöperative research—and there are many of them—have recognized that this coöperative attack must not be designed to deprive any of the individual companies of the reward for foresight or for individual effort. If, for example, one company has developed a trade secret from which it derives benefit, a proposal that the industry should combine to discover that trade secret by means of research would not be tolerated either by the company that would be injured or by any other fair-minded member of the industry. This does not in any way imply that any individual company in the industry would not have the right, through its own efforts and at its own expense, to try to either duplicate or surpass the trade secret held by its rival. At present "geophysical instruments and methods" seem to be distinctly in the field that pertains to the individual company rather than to the industry as a whole, even although it is yet too early to determine whether, from an economic standpoint, they will prove to be of great benefit.

There have been other criticisms, comments, and suggestions. All have been welcomed, for even criticism demonstrates that the program is being studied with interest, though that interest may be hostile. Some of the criticisms have been truly constructive and helpful. All have received thoughtful consideration.

In conclusion, the writer would reiterate a belief that the American Association of Petroleum Geologists includes in its membership men who are fitted by natural endowment, by training, and by experience, to be leaders in modern geologic thought; that the Association itself, which is the largest and most active geological organization in the world, should and can be a great and recognized force in the development and perfection of our science; and that to achieve and hold a position in keeping with the nature and size of our organization and the character and ability of the men who comprise it, we should actively support and vigorously prosecute research on the fundamental problems of the geology and the production of petroleum.

DISCUSSION

CRETACEOUS AND TERTIARY OF SOUTHERN TEXAS AND NORTHERN MEXICO

The Texas University has just published *Bulletin 2748*, containing papers entitled "The Cretaceous and Tertiary of Southern Texas and Northern Mexico," by Emil Böse and O. A. Cavins, and "Cretaceous Ammonites from Texas and Northern Mexico," by Emil Böse. The paleontological work in this bulletin is very valuable and it is well supplied with plates and descriptions. Unfortunately, in the subdivision of the Cretaceous, European nomenclature was used. The subdivisions are made almost entirely on the basis of fauna, which is generally impractical in making field subdivisions in a section where fossils are, as a rule, poorly preserved.

Wrong conclusions published by eminent men may be retained in the literature for years after local workers have disproved them. Many of these conclusions are incorporated in textbooks. For that reason I wish to call attention to certain of the conclusions in this bulletin which seem to be in error. I do this without wishing to detract from the value of the publication, which is real.

In the division of the Tertiary, for which the authors are in no way responsible, the so-called Bigford formation is included and placed in the Wilcox. I consider this designation a misnomer; it was first adopted by Trowbridge, in an attempt to account for the great narrowing in the outcrop of the Carrizo sandstone along the Rio Grande. At this place the Carrizo sandstone is probably quite as thick as it is farther north and the thinning of the outcrop is due to increase in dip. The so-called Bigford I believe to be a part of the Mount Selman.

The authors make the statement that the "main mountain folding of the Sierra Madre occurred during lower or middle Eocene." I agree with them that the Tamaulipas arch was folded before the Sierra Madre, but do not concur with their theory as to the age of the folding. In northern Mexico material derived from the Cretaceous limestones which make up the Sierra Madre, is extremely rare in the Eocene. It does not occur plentifully until Reynosa time, which has been tentatively placed in the Pliocene by several authors. Near the Sierra Tamaulipas there is some material in the Oligocene and possibly also in the upper Eocene derived from the Cretaceous limestones of the mountains near by. The great amount of sandy material in the Eocene could not have been derived from the Sierra Madre, which is made up almost exclusively of massive limestones. This material must have been derived from a distant source, either western Texas or southern New Mexico, or from the Sierra Madre Occidental in western Chihuahua and Durango. Had the main movement in the Sierra Madre occurred during lower and middle Eocene, the formations in the area near by certainly would have contained a great quantity of material derived from them.

The statement that the Chicontepec beds are the only representatives of the Eocene in northern Vera Cruz—and they not certainly of that age—is, I believe, an error. On the eastern side of the Tempoal valley there is a great thickness of Tantoyuca beds carrying many *Venericardia*, which have been considered Eocene in age.

In the paleogeographic map accompanying the bulletin, an Oligocene continent is mapped through northern Tamaulipas. In that area beds of considerable thickness have been found similar to those described by Bailey as Gueyden from south Texas, and by Deussen as Catahoula from central Texas. Although fossils have not been found in them, their Oligocene age seems certain. Bailey gives these beds an estimated thickness of 850 feet in Duval County, Texas, and there is reason to believe that they are thicker in northeastern Mexico.

J. L. TATUM

MARLAND OIL COMPANY
LAREDO, TEXAS
July 12, 1928

WATER PROBLEMS IN THE NEW GROSNY FIELD, RUSSIA

In the *Bulletin* for October, 1927, Norbert T. Lindtrop contributed a paper on "Outline of Water Problems in the New Grosny Field, Russia."

The author cites a very interesting case of rapid depletion of sulphates in an oil-well brine which is associated with oil. This depletion is accompanied by a corresponding increase of carbonate. The oil production of the well cited, during a period of four years, dropped from 8,000 barrels per day to 20 barrels per day. The operators decided to deepen the well, but before this was done the well was shut in for 3.5 months, at the end of which time the water was examined. It was found that the sulphate (SO_4) milligram equivalents dropped from 8.0 to zero, and that the carbonate (CO_3) milligram equivalents increased from 5.42 to 12.2. The well was then pumped 20 hours with the result that the sulphate (SO_4) increased from zero to 2 and the carbonate decreased from 12.2 to 9.6, and after pumping the well two days the brine resumed the characteristics possessed before the well was shut in.

It seems to the writer that the author infers that this sulphate depletion is the result of chemical reduction, the oil being in contact with a hot brine, the temperature of which was approximately 190° F. The author does not mention the presence or absence of hydrogen sulphide or sulphides, neither does he give any other evidence supporting this "reduction" theory. The writer does not know of any laboratory results showing reduction of sulphates due to inanimate organic matter even at temperatures of 572° F. and higher.

The biological process of sulphate reduction next presents itself, and only with difficulty is it possible to conceive of micro-organisms having the power of reducing approximately 400 pounds of sulphate (SO_4) per million pounds of brine through the short duration of 3.5 months and it is equally difficult to conceive of micro-organisms being thermophilic to the extent of withstanding this temperature of 190° F.

The premise of witherite occurrence in the horizons above the oil sands would account for changes in the brine similar to the evidence set forth by the author. The solubility of witherite (barium carbonate) at 190° F. is estimated at 40 to 50 parts per million; thus water from above the oil-carrying witherite in solution, coming in contact with the sulphate water below, would cause the precipitation of the sulphate as barium sulphate, accompanied by the increasing of the carbonate of the water. The author gives no information as to the constitution of the solids which may or may not have been carried by the bottom settlings. A few years ago L. G. E. Bignell submitted barium sulphate pellets which were taken from a producing well in Texas. This barite no doubt resulted from the contact of a sulphate water with a water bearing barium, and the pellet form was due to the agitation in the hole.

It is clear that the chemical precipitation process, or possibly the biological reduction process, is the more probable cause of the sulphate depletion mentioned by the author.

Students of hydrology will appreciate Mr. Lindtrop's paper and it is hoped that the author will give us additional information relative to the cause of this sulphate reduction in the Grosny field.

R. L. GINTER[1]

THE TULSA LABORATORIES, INC.
TULSA, OKLAHOMA
July, 1928

[1]Introduced by Robert H. Dott.

THE SO-CALLED "LOWER SILURIAN" FOSSILS OF VENEZUELA

In 1904,[1] Fr. Drevermann described *Calymene senaria* auctt. and *Orthoceras* cf. *olorus* Hall from a collection obtained by a marine engineer, Wilhelm Klein, while traveling from Caracas by way of Valencia to Puerto Cabello. This was a remarkable discovery, if true, and the paper therefore attracted the attention of the writer, who prepared a notice of it for the *American Journal of Science*,[2] in the course of which he said: "As no Ordovician formations are known in northern South America, the reviewer raises the question—Are these fossils probably of Silurian age?" He compared them with well-known Niagaran forms and concluded: "All in all, I feel that the Venezuelan fossils are of Upper Silurian age." Drevermann again looked up the fossils and stated in a letter to the writer that he was not certain of their age.

Later Professor Suess wrote Professor Salomon, who had the fossils, suggesting that he look into this matter once more, and ascertain if the fossils actually came from Venezuela, since their occurrence in that country seemed improbable. The collector was asked to state just where he obtained these specimens and replied that they might not have come from Venezuela but might have been purchased in Newport News, Virginia! Accordingly Salomon concluded that it would be best to disregard the fossils.

[1]*N. Jahrb. f. Min.*, etc., Vol. 1 (1904), pp. 91-93.

[2]Vol. 19 (1905), p. 197.

Recently, R. A. Liddle, not knowing these facts, again cites the now celebrated fossils in his valuable book, *The Geology of Venezuela and Trinidad* (Fort Worth, Texas, 1928). This led the writer to ask for the loan of the specimens, which Professor Salomon readily granted. Both fossils occur in a fine-grained blue-gray unmetamorphosed dolomite such as is known nowhere in Venezuela, but is exactly like that at Joliet, Illinois, where it is Niagaran in age. There seems to be no doubt that the two specimens—one the common *Calymene niagarensis* Hall, the other a form of *Dawsonoceras annulatum* (Sowerby)—came from these Niagaran dolomites that are quarried so extensively in the vicinity of Joliet. Hence there is as yet no proved Silurian in Venezuela, and certainly none in the metamorphic series of the Coast Range.

CHARLES SCHUCHERT

YALE UNIVERSITY
NEW HAVEN, CONNECTICUT
August 3, 1928

CORRECTION

EXPERIMENTS IN OVER- AND UNDER-THRUSTING

In the paper on "Relationship Between Over- and Under-thrusting as Revealed by Experiments" by Theodore A. Link in the August *Bulletin*, the following corrections should be made:

On page 847, lines 5 and 6, the sentence, "However, be this as it may, the predominance of *under*thrusts is firmly established as far as these experiments are concerned," should read, "However, be this as it may, the predominance of *over*thrusts is firmly established as far as these experiments are concerned."

On page 848, line 15, the words, "planes *for* folding," should read, "planes *of* folding."

RAINBOW CITY FIELD, UNION COUNTY, ARKANSAS

The location of wells in the Rainbow City field given in the geological note of the same title by W. C. Spooner in the July *Bulletin*, pp. 763-64, as T. 14 S., R. 11 W., should be T. 17 S., R. 14 W.

REVIEWS AND NEW PUBLICATIONS

Die Magnetische Verfahren der Angewandten Geophysik (The Magnetic Method of Applied Geophysics). By HANS HAALCK. Gebrüder Borntraeger, Berlin, 1927. 150 pp., 61 figs., 3 plates. Price, 12 M.

This book is a rather thorough elementary discussion of the modern applied magnetic methods of geophysical prospecting from the physical-geophysical side rather than the geological-geophysical side. Geologists and mining engineers who have the practical task of conducting magnetic surveys will lament the absence of a detailed discussion of the operation of magnetic surveys and of the geological interpretation of the results of magnetic surveys. But the geologist, mining engineer, or layman who can read easy scientific German can get from this book an intelligent conception of what this magnetism is, of its relation to terrestrial magnetism, of the instruments used or usable in practical field surveys, of certain elementary principles regarding the anomalies produced by simple types of bodies, and of certain elementary theoretical principles of the cause of local anomalies. Some of Haalck's formulæ are challenged by Slichter. A list is given of thirty-three surveyed anomalies in relation to the known causes. Kurst is described as an example of a strong magnetic anomaly and the Wefensleben salt dome ridge as an example of a weak anomaly. An extensive bibliography is given. Although the book will be of most use to students of elementary geophysics, the advanced student will find it valuable as a reference book. The reviewer finds it a welcome addition to his library and is glad to recommend it.

DONALD C. BARTON

CONSULTING GEOLOGIST AND GEOPHYSICIST
Houston, Texas

Kohlenpetrographisches Praktikum (A Summary of Coal Petrography). By ERICH STACH. Gebrüder Borntraeger, Berlin, 1928. 196 pp., 64 figs. Price, 10.80 M.

This well-organized book gives a clear picture of the present status of coal petrography. Nearly half (88 pages) is devoted to a description of the different petrographic methods now in use. The making and interpretation of ash-skeletons of coal fragments, and several methods of maceration are first discussed. Thin-section cutting and grinding processes, as practiced by Jeffrey, Thiessen, Lomax, and other masters of the art, are clearly described. The author mentions that Henry Witham published an account of an investigation of coal by means of thin sections in 1831-32. This was 20 years before the appearance of Sorby's first paper on sedimentary petrography, and 27 years before the publication of the paper that finally attracted some attention to the

new method of research. Dr. Stach gives a good account of microchemical methods, with notes on the results that may be secured by their use. The different methods of etching and treating polished surfaces are fully described. One of the most useful is a recent invention of the author himself. Using a polished surface, he brings out just the right amount of relief by treatment with a special variety of alumina. According to the claims of the author, which are effectively corroborated by many beautiful microphotographs reproduced in the book, this method is not only the simplest and most readily used of all, but is applicable to all types of coal, usually without any preliminary treatment. Its adoption by other workers will doubtless bring about a rapid accumulation of important data concerning the structure of coals. X-ray methods, on the other hand, have so far proved useful only in studying the distribution of ash in coals. This part of the book closes with an account of microphotography as applied to coal preparations.

The latter half of the book treats of the fundamental constituents of coal, and of their mutual relations in anthracite, bituminous coal, and other varieties. The author insists that all coals, with the possible exception of the bogheads, are composed essentially of just three constituents, vitrain (glance coal, or anthraxylon), durain (dull coal, mat coal, equivalent to the "attritus" of Thiessen with associated fragments of spores and other resistant materials), and fusain (mineral charcoal, etc.). Whether or not it will meet with the approval of other coal specialists, his discussion of the petrographic characters of these substances, their interrelations, and their origin, is clear and interesting. Vitrain is considered to be a coalified wood with the cells filled by colloidal humic substances. Durain consists of spore fragments imbedded in a groundmass of decomposed and structureless plant material. Fusain, considered by many to be a charcoal, is of doubtful origin. The author favors the hypothesis that it is slightly decomposed woody material impregnated and preserved by concentrated humic substances. It grades into vitrain, from which it is distinguished by its well-preserved cell structure.

Anthracite is said to be composed of more or less lustrous vitrain with a lesser amount of fusain and some "anthracitic" durain. Bituminous coal consists essentially of vitrain and durain in more or less equal proportions, the amount of fusain being commonly minor. Cannel coal is petrographically a durain. In his discussion of boghead coal, the author hesitates between R. Petonié's colloidal hypothesis and the algal hypothesis of Thiessen. Lignites (*Braunkohlen*) are variable and have been exhaustively studied in Germany, especially by Gothan. The author's account of their characteristics is too complex to be summarized here.

The book concludes with two brief chapters, one on the methods of distinguishing lignite from bituminous coal and from peat, the other on the petrographic investigation of coal briquets. A final attractive feature is a bibliography of 336 titles.

In spite of the somewhat special field it covers, this book will interest many geologists who are not primarily concerned with the study of coal. From the petrographic point of view, perhaps the most striking feature is the extensive use that has been made of polished surfaces. This method, applied successfully to the investigation of sedimentary rocks by Delesse 60 years ago, has

more recently been almost exclusively given over to students of metals and opaque ores. Its simplicity, the ease with which comparatively large surfaces may be prepared and studied, and the many secondary methods that may be combined with it, make it seem worthy of more consideration than it ordinarily receives. Some of our oil shales may turn out to be peculiarly adapted to this method of investigation.

R. D. REED

ALHAMBRA, CALIFORNIA
June, 1928

The Story of Geology. By ALLAN L. BENSON. 300 pp., 40 full-page illustrations, bibliography of 32 references. Cosmopolitan Book Corporation, New York, N. Y., 1928.

This very readable book was written by a well-read newspaper and magazine writer. He has followed standard texts and books by well-known geologists, and he reduces their technical language to a simple, yet entertaining story. The book gives an excellent view of physical geology to the layman, and an equally good review to the working geologist. No mention is made of stratigraphic geology.

Chapter I is devoted to various earth theories, including the nebular and planetesimal hypotheses, the theory of continental drift, and earth movement.

Chapter II concerns the Pleistocene ice age, its effects, the formation and history of the Great Lakes, and theories regarding the causes of the ice ages.

In Chapter III the author mentions certain phases of erosion, discussing the Grand Canyon and the Mammoth Cave; giving inferences concerning the interior of the earth and radio-activity, and making a brief mention of fossils, soils, and crystals.

Chapter IV is on volcanoes and earthquakes, several of the American earthquakes being described in some detail.

Chapter V concerns the ocean, its temperatures, character, life, and tides.

Chapter VI is devoted to meteorology.

In the last four chapters the author discusses life on the earth, giving a lucid résumé of the development of organisms from the simplest forms, tracing the progression of plants from bacteria to flowering plants, and animals from protozoa to man, with considerable discussion of the vertebrates, and the ancestry of man.

The discussions are entirely in accord with the latest geological thought. With one exception, the theories which he sets forth are probably held by all geologists. His assumption that the theory of continental drift is generally accepted does not seem, to the reviewer, to be entirely justified.

The book is written in the breezy style of the newspaper writer, and is very easy reading.

ROBERT H. DOTT

TULSA, OKLAHOMA
July 30, 1928

The Geology of British Honduras. By LESLIE H. OWER. Colonial Secretary's office, Belize, British Honduras, July, 1928. 24 pp. and folded map. Price, $0.25.

This is the first official publication on the geology of British Honduras. It is accompanied by a map in three colors showing the topography and geology, scale 1 : 1,000,000. The rocks are Upper Carboniferous (Permian?) slates intruded by granite porphyry, Oligocene white limestones, Miocene marls and shales, and Recent coral reefs. It is concluded that the chances of finding oil are meager, because the Oligocene limestones are not supposed to be source rocks and they are not known to overlie any source rock.

SIDNEY POWERS

TULSA, OKLAHOMA
August 3, 1928

RECENT PUBLICATIONS

FLORIDA

"The Molluscan Fauna of the Alum Bluff Group of Florida, Part V, Tellinacea, Solenacea, Mactracea, Myacea, Molluscoidea," by Julia Gardner. *U. S Geol. Survey Prof. Paper 142-E.* Pp. i-iv, 185-249, i-iii, plates 29-36. Washington, D. C., 1928. Free.

GENERAL

The following publications of the U. S. Bureau of Mines may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C.:

"Tabulated Analyses of Representative Crude Petroleum of the United States," by N. A. C. Smith and E. C. Lane. *Bulletin 291.* 69 pp. Price, $0.15.

"Petroleum in 1926," by G. R. Hopkins and A. B. Coons. Separate chapter, *Mineral Resources of the United States.* 83 pp. Price, $0.15.

GEOPHYSICS

"Geophysikalische Schürfungen auf Erdöl" (Geophysical Prospecting for Petroleum), by Norbert Gella. *Zeitschrift für Praktische Geologie,* April, 1928. Pp. 49-54; 7 figs.

"Adaptation of Magnet Instruments and Methods to Economic Geology," by E. Pautsch. Part 1, *Oil Weekly,* July 13, 1928, pp. 48-54, Figs. 1-10; Part 2, July 20, 1928, pp. 43-47, Figs. 11-17.

The American Institute of Mining and Metallurgical Engineers has issued the following *Technical Publications* in *Class L, Geophysical Prospecting:*

"A New Micromagnetometer," by Frank Rieber. *Tech. Pub. 119.*

"Certain Aspects of Magnetic Surveying," by Louis B. Slichter. *Tech. Pub. 120.*

"Certain Applications of the Surface Potential Method," by Warren Weaver. *Tech. Pub. 121.*

"Russian Papers on Measurements of Terrestrial Radioactivity," by F. W. Lee. *U. S. Bureau of Mines Information Circular 6022.* 27 pp. and bibliography. Washington, D. C. Free.

LOUISIANA

Eighth Biennial Report of the Department of Conservation of the State of Louisiana, 1926-1928, V. K. Irion, Commissioner, New Orleans. Contains report of the division of minerals, by W. F. Chisholm, director, giving production figures of oil and gas for all fields in the state. 341 pp., illus.

Oil and Gas Fields of Louisiana. Map by the State Department of Conservation, Minerals Division, W. F. Chisholm, director, Shreveport, 1928. Location of oil and gas fields on base map of the U. S. Geological Survey. Scale 1 : 500,000.

MISSISSIPPI

"The Ground-Water Resources of Mississippi," by Lloyd W. Stephenson, William N. Logan, and Gerald A. Waring. *U. S. Geol. Survey Water-Supply Paper 576.* Prepared in coöperation with the *Mississippi State Geol. Survey.* Contains chapter on general geology, pp. 27-63. 515 pp., 3 figs., 12 plates, 1 insert. Superintendent of Documents, Government Printing Office, Washington, D. C., 1928. Price, $0.90.

NEW JERSEY

"The Eocene Age of the Supposed Late Upper Cretaceous Greensand Marls of New Jersey," by C. Wythe Cooke and Lloyd W. Stephenson. *The Journal of Geology*, Vol. 36, No. 2 (February-March, 1928). Pp. 139-48. Univ. of Chicago Press, Chicago, Illinois.

OKLAHOMA

The following publications may be secured from the Oklahoma Geological Survey, Norman, Oklahoma:

"Digest of Oklahoma Oil Fields," by Bess Mills-Bullard. *Bulletin 40-Q.* 180 pp., index, and map. Price, $1.10.

"Geology of Comanche County," by Frank Gouin. *Bulletin 40-DD.* 25 pp., maps. Price, $0.30.

PERSIA

"Gisements pétrolifères de la Perse," by C. -P. Niclesco. *La Revue Pétrolifère*, July 14, 1928. Contains a double-page map showing the location of petroleum indications of Persia and adjoining regions.

THE ASSOCIATION LIBRARY

Headquarters acknowledges library accessions:

TEXAS

From O. A. Cavins:

"The Cretaceous and Tertiary of Southern Texas and Northern Mexico," by Emil Böse and O. A. Cavins.

"Cretaceous Ammonites from Texas and Northern Mexico," by Emil Böse.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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FOURTEENTH ANNUAL MEETING, FORT WORTH, TEXAS, MARCH 21, 22, 23, 1929

The Fort Worth Geological Society, B. E. Thompson, president, has appointed the following committees to make arrangements for the fourteenth annual meeting of the Association, to be held in Fort Worth, March 21, 22, and 23, 1929.

GENERAL COMMITTEE

J. Elmer Thomas, chairman, 602 Fort Worth Club Building

Ford Bradish	J. H. Jenkins
J. Earle Brown	R. A. Liddle
David Donoghue	B. E. Thompson
H. B. Fuqua	C. P. Watson

FINANCE

J. H. Jenkins, chairman, Tidal Oil Company, W. T. Waggoner Building

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PROGRAM

R. A. Liddle, chairman, The Pure Oil Company, Box 1007
Paul L. Applin A. R. Denison F. B. Plummer
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ENTERTAINMENT

J. Earle Brown, chairman, Tidal Oil Company, W. T. Waggoner Building
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PUBLICITY

Ford Bradish, chairman, 1205 W. T. Waggoner Building
A. Bruyere N. B. Livingston R. J. Metcalf

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H. B. Fuqua, chairman, Gulf Production Company
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VISITING LADIES

C. P. Watson, chairman, 4123 West 7th Street

REGISTRATION

David Donoghue, chairman, Texas Pacific Coal and Oil Company
E. B. Stiles W. W. Patrick

ARRANGEMENTS

B. E. Thompson, chairman, Box 737
Claude Dally C. E. Yager

The program committee is planning a symposium on the geology of the southwestern part of the Mid-Continent region and will attempt something in the way of an innovation in the presentation of papers, the full details of which will be announced soon. A special effort will be made to have not only abstracts but complete papers in mimeographed form for the use of members attending the meetings. It is also planned to have manuscripts submitted early enough so that prepared discussions may be mimeographed for use at the meeting.

Authors are requested to submit abstracts of proposed papers early in January, and the full manuscript as soon as possible thereafter. Papers presented on the program are the property of the Association, for publication only in the Bulletin of the Association, unless arrangements to the contrary are made with the business manager. Abstracts and manuscripts intended for the Fort Worth meeting should be sent to R. A. Liddle, Box 1007, Fort Worth, Texas.

AT HOME AND ABROAD

The Association is again participating in the International Petroleum Exposition which is to be held at Tulsa, Oklahoma, October 20-29. The A. A. P. G. booth, space for which is donated by the exposition management, will be located in the building housing the educational and technical exhibits. Geologists are requested to register at the A. A. P. G. booth. The attendance of geologists and engineers last year was very encouraging to the directors in their efforts to make the exposition primarily an educational and technical display of oil-field equipment and methods. The Committee in charge of scientific exhibits is composed of ALF G. HEGGEM, chairman, CHARLES N. GOULD, FRANK C. GREENE, LUTHER H. WHITE, LYNDON L. FOLEY, SIDNEY POWERS, W. L. FOSTER, W. VAN HOLST PELLEKAAN, R. S. MCFARLAND, JAMES H. GARDNER, C. K. FRANCIS, EARL A. TRAGER, and R. C. BECKSTROM. Railroads have granted reduced fares. You should request return certificate when purchasing your ticket.

The fall meeting of the Petroleum Division of the A. I. M. E. will be held at Tulsa, on October 18 and 19, just preceding the opening of the International Petroleum Exposition. The technical program of the division is in part as follows: Measurements of Original Pressure, Temperature and Gas-Oil Ratio in Oil Sands, by K. C. SCLATER; Capillary Phenomena as Related to Oil Production: A Discussion of Conditions in the Oil Reservoir that Have Relation to Rate of Production and Ultimate Production, by F. G. TICKELL; The Oil Recovery Investigations of the U. S. Bureau of Mines, by R. VAN A. MILLS and JOSEPH CHALMERS; Repressuring During the Early Stages of Development, by C. E. BEECHER; Deep Well Drilling, by R. S. CARTWRIGHT; Intermittent Injection of Gas in Gas-Lift Installations, by MORGAN WALKER; Supply and Demand of Petroleum during 1928 (author to be selected); Deep Well Pumping in California, by H. N. MARSH; and Pumping Wells in the Seminole Oil Fields, Oklahoma, by M. J. KIRWAN.

NICHOLAS W. SHIARELLA, geologist of Owensboro, Kentucky, has returned from a trip into Mexico and Central America.

F. H. MCNUTT, of San Antonio, Texas, is specializing in the development of potash prospects. Mr. McNutt recently returned from a business trip into New Mexico.

R. C. BECKSTROM has resigned his position as head of the department of petroleum engineering at the Colorado School of Mines to become dean of the School of Petroleum Technology recently established at the University of Tulsa, in Oklahoma.

The West Texas Geological Society and the Bureau of Economic Geology of the University of Texas held jointly a geologic excursion and conference in the Van Horn-El Paso region of Texas and Mexico, July 1-3. The geologists

assembled at Van Horn on the evening of June 30. Exposures were examined in the Malone, Finlay, Diablo, and Franklin mountains of Texas. Cretaceous exposures were examined in the mountains south of Juarez in Mexico. Guides on this excursion were J. W. BEEDE, C. L. BAKER, B. R. HAIGH, and L. A. NELSON. FRANK E. LEWIS was chairman of the committee on arrangements. Among visiting geologists was N. H. DARTON of the United States Geological Survey. Seventy-three participated in the excursion.

On the afternoon of June 23 a meteor of exceptional brilliancy was observed in southwestern Texas, being overhead probably in the northwestern part of Uvalde County. It appeared as a "ball of fire" followed by a "cloud of smoke" marking its path across the heavens. Although falling on a bright sunshiny afternoon this meteor was seen over a large part of Texas and the noise of it was heard in four or five adjacent counties. E. H. SELLARDS of the University of Texas is recording the observations made on the meteor. It has not yet been shown that the meteor reached the earth. Observations on the meteor were made at Uvalde by F. M. GETZENDANER.

JOHN M. LOVEJOY is president of The Petroleum Bond and Share Corporation of New York.

The western sections of the A. I. M. E., the western division of the American Mining Congress, and the California Development Association will hold a joint meeting in Los Angeles, California, September 10-13.

MALVIN G. HOFFMAN, formerly with the Marland Oil Company of Ponca City and the Carter Oil Company of Tulsa, Oklahoma, has completed three years of postgraduate work in geology and has passed the examination for the degree of doctor of philosophy. Mr. Hoffman specialized in sedimentary petrography, X-ray analysis of crystal structure, and the physical chemistry of magmatic differentiation. His address is 5449 Cornell Avenue, Chicago, Illinois.

CHARLES E. STRAUB of Wichita, Kansas, geologist in charge of activities of the Dixie Oil Company, Inc., in Kansas and north-central Oklahoma, since their inception three years ago, has left that company. WALTER W. LARSH, formerly assistant geologist, is now in charge.

EVERETT CARPENTER, formerly chief geologist for The Empire Gas and Fuel Company, of Bartlesville, Oklahoma, is doing some special research work on helium for The Kentucky Hydrogen and Oxygen Company, of Louisville, Kentucky.

SAMUEL BYRNE BROWN, JR., who recently spent several years as geologist and oil and gas engineer with The Philadelphia Company, working in the Appalachian and Interior fields, is associated with W. ARMSTRONG PRICE, 808 Esperson Building, Houston, Texas. Mr. Brown is the son of Samuel Byrne Brown (deceased) who was for many years head of the department of geology at West Virginia University. Mr. Brown assisted in the valuation of the gas reserves of Saxet Gas Company in the Saxet, White Point, and Refugio fields, and in the valuation of the Texas Gas Utilities Company gas supply, distributing system, and 11-mile pipe line, now under construction, which will supply the town of Uvalde. Other recent valuation studies made by Mr. Price were

on the gas supply of the Big Spring Public Service Company from the Roberts field, Howard County, Texas, and on the Petrolia oil field.

GEORGE A. ELLEDGE, formerly geologist for the Cortez Oil Company in Mexico, is assisting W. Armstrong Price in a detailed survey of the extensive lands of Lynch Davidson and Company, lumber operators. This study covers the northern third of Polk County in the Neches River drainage, Texas.

JAMES H. HANCE has resigned from the department of geology in the Agricultural and Mechanical College of Texas to become dean of the School of Mines, Oregon State College, Corvallis, Oregon.

L. M. MCNAUGHTON, recently geologist with the Humble Oil and Refining Company in East Texas, has joined the Rycade Oil Corporation as geologist at Houston.

DEAN E. WINCHESTER, consulting geologist of Denver, Colorado, and HARRY K. SAVAGE, mining engineer, have an article on "Government and Future Oil Supply" in the *Oil and Gas Journal* for August 2.

Mr. and Mrs. E. B. STILES announce the arrival of Miss Emily Elisabeth Stiles on Sunday, July 29, 1928, at their home, 4608 Birchman Street, Fort Worth, Texas. Mr. Stiles is with The Pure Oil Company at Fort Worth.

J. S. ROSS, of the U. S. Bureau of Mines at Midwest, Wyoming, has been transferred to Shreveport, Louisiana, to take charge of the bureau's temporary station and to conduct a study of the Trinity formation at Cotton Valley. The work is in coöperation with the local operators and the minerals division of the State Conservation Department.

Mr. and Mrs. DONALD C. BARTON recently sailed on the S. S. Hamburg for a short combined pleasure and business trip to London, Paris, and Berlin. They return late in September.

H. G. SCHNEIDER has been made chief geologist of the Dixie Oil Company. His office is in the Slattery Building, Shreveport, Louisiana.

GEORGE D. MORGAN of the Dixie Oil Company, formerly stationed at San Antonio, Texas, has been made vice-president in charge of land and geological departments. Mr. Morgan has moved to the Shreveport offices of the company.

R. E. SOMERS has resigned as head of the department of geology at the University of Pittsburgh to join the geological staff of the Gulf Oil Corporation at Pittsburgh, Pennsylvania.

JOE W. WEST of Purcell, Oklahoma, formerly with the Colombian Oil Concessions, has returned to the United States after eight months of experience in Colombia.

DOSKA MONICAL, micro-paleontologist for the Shell Company of California, and PAUL L. HENDERSON, former geologist for the Standard Oil Company of California and now vice-president of the General Pacific Company, were married August 11, at the home of DONALD D. HUGHES, Glendale, Cali-

fornia. Mr. and Mrs. Henderson will live in Seattle for a few months and then make their permanent home in San Francisco.

The Fifteenth session of the INTERNATIONAL GEOLOGICAL CONGRESS will be held at Pretoria, South Africa, from July 29 to August 7, 1929. Excursions will be held before and after these dates. The subjects for discussion will be: (1) magmatic differentiation, (2) pre-Pleistocene glacial periods, (3) the Karroo system, (4) the genesis of petroleum, and the geological work of micro-organisms. The membership fee is £1 sterling, payable in advance. Membership forms can be secured from the General Secretary, Box 391, Pretoria. A reduction of 20 per cent on steamship rates has been granted to members of the Congress. It is highly desirable that all those wishing to attend the Congress or wishing to submit papers should apply as soon as possible, because the applications for the excursions will not be received later than April 1 and steamship arrangements must be made at an early date. Papers for publication must be submitted on or before July 15, 1929, and an abstract of not more than 200 words not later than June 1, 1929.

HUGH A. STEWART, geologist with The Texas Company at Denver, Colorado, has an article on "Functions and Qualifications of the Oil Geologist" in a recent number of the Colorado School of Mines Magazine. It was reprinted in the August *Oil Bulletin* of the Chamber of Mines and Oil at Los Angeles, California.

CARROLL M. WAGNER, geologist with the General Petroleum Corporation at Los Angeles, published a paper on "Application of Commercial Aviation to a Geological Survey" in *Doings in General*, which was reprinted in the *Oil Bulletin* for August.

WESLEY G. GISH, chief geologist of the Sinclair Oil and Gas Company, moved from the Tulsa office to the Fort Worth office, September 1, to be in charge of the land and geological work of the company in the Texas district, which includes Texas (except the Gulf Coast), northeastern Louisiana, and southwestern Arkansas.

C. A. YOAKAM, recently Seminole district geologist for the Sinclair, has been given charge of the company's geological work in Oklahoma and Kansas, with headquarters at Tulsa.

The Division of Geology and Geography of the National Research Council, Washington, D. C., is receiving pledges of financial support for an "Annotated Bibliography of the International Literature of Economic Geology," which it is proposed shall be published semi-annually by the Economic Geology Publishing Company. This bibliography is to include lists of new publications with concise statements or abstracts of each. The field to be covered is economic geology in all branches. According to the present plan, pledges may be made in three annual installments and are to be contingent upon the total subscription of at least $18,000. Inasmuch as there is now no abstract journal in English wholly devoted to economic geology, this proposal to meet a real need in this country should receive the full support of economic geologists.

Coöperative Research of the Permo-Carboniferous Formations of the Mid-Continent is a project being undertaken by the geologists of that region as the result of a meeting called at Norman, Oklahoma, May 19, 1928, by CHARLES N. GOULD, state geologist of Oklahoma. The work is being carried on under the auspices of the Society of Economic Paleontologists and Mineralogists, F. B. PLUMMER, secretary-treasurer, 1205 W. T. Waggoner Building, Fort Worth, Texas. The purpose of this movement is to provide correct and extensive correlation of Pennsylvanian and Permian stratigraphy. At the Norman meeting, RAYMOND C. MOORE, state geologist of Kansas, was chosen director to organize and coördinate the work. Dr. Moore appointed regional chairmen as follows: G. E. CONDRA for Nebraska; FRANK GREENE for northern Oklahoma; C. W. TOMLINSON for southern Oklahoma; and F. B. PLUMMER for Texas. After the meeting Dr. Moore requested local geological societies to join in the enterprise and to appoint local committees to work with the regional chairmen.

The Texas committees to further coöperative investigations of the Permo-Carboniferous met at the New Connellee Hotel, Eastland, Texas, July 14. Sixty-one representatives were present from all interested societies in the state, the Bureau of Economic Geology, and the Texas Christian University. The following projects were endorsed: (1) compilation of a new outcrop map of the Permian and Pennsylvanian strata of Texas; (2) detailed study of the fauna of certain of the more important horizons, such as the Wayland shale or the Coleman Junction beds, this study to be extended as far as the zone could be correlated across Oklahoma and into Kansas or beyond; and (3) detailed study of the Pennsylvanian sands and conglomerate. The work of securing and assembling the information for the map was distributed among individuals in the several districts, such as Wichita Falls, Fort Worth, Cisco, Abilene, San Angelo, and Amarillo. The general committee for Texas is composed of F. B. PLUMMER, chairman, FORD BRADISH, secretary, and R. C. MARTIN, publicity. The district chairmen for Texas are: H. B. FUQUA, Fort Worth; J. M. ARMSTRONG, Eastland; W. G. WENDER, Cisco; O. F. HEDRICK, Thurber; T. F. NEWMAN, Abilene; M. G. CHENEY, Coleman; R. L. CANNON, San Angelo; W. E. THOMPSON, Wichita Falls; C. DON HUGHES, Amarillo; E. H. SELLARDS, Austin; and WILLIS STORM, Dallas.

J. ELMER THOMAS, geologist and producer of Fort Worth, Texas, has become associated with Fenner and Beane, members of the New York Stock Exchange. Mr. Thomas will retain his headquarters at Fort Worth.

CHARLES A. PISHNEY, of the engineering department of the Marland Oil Company, has been transferred from Fort Worth, Texas, to Ponca City, Oklahoma.

JAMES O. G. SANDERSON, recently teaching and studying at the Royal Ontario Museum of Paleontology at Toronto, is now with Imperial Oil, Limted, 602 2nd Street, W., Calgary, Alberta, Canada.

FOREST R. REES, formerly with the Devonian Oil Company and recently engaged in geological work in the San Angelo district of Texas, returned to Tulsa, Oklahoma, in August.

JOHN L. RICH, consulting geologist of Ottawa, Kansas, third vice-president of the A. A. P. G., in charge of editorial work, visited several of the eastern oil fields last summer.

DAVID DONOGHUE, a director of the Texas Pacific Coal and Oil Company at Fort Worth, Texas, and second vice-president of the A. A. P. G., was in Santa Fé, Shiprock, and Carlsbad, New Mexico, and Alpine, Texas, in August.

JOSIAH BRIDGE, associate professor of geology in the Missouri School of Mines, has been appointed research professor at Princeton University.

FREDERICK G. CLAPP has completed his engagement as petroleum engineer to the Imperial Government of Persia. He will continue his consulting practice and can be addressed as usual at 50 Church Street, New York City.

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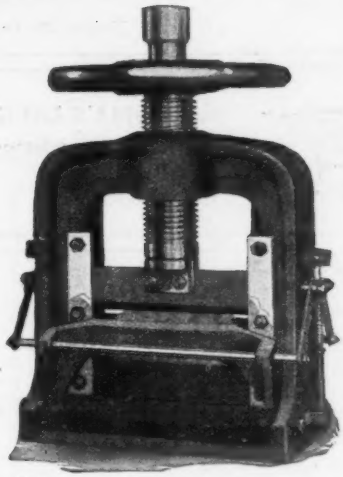

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